ABSTRACT

Suksangpanya, Nobphadon. Ph.D., Purdue University, December 2016. Fracture Analysis in Biomimetic Bouligand Architectures. Major Professor: Pablo D. Zavattieri.

The Bouligand structure is a hierarchical structure that uniaxial fibers layers resembled periodically into a helicoidal architecture which is found in many biological materials. Many studies have shown high damage resistant performance in the Bouligand structures and its biomimetic materials. One of the outstanding species with the Bouligand structures is the smashing Mantis Shrimp, *Odontodactylus Scyllarus*, (or stomatopod) due to its capability of generating high speed, high acceleration blows using its raptorial appendage to defeat highly armored preys. The loading bearing part of this appendage, the dactyl club, contains a large region which is mainly characterized by the Bouligand structure. This region is capable of developing a significant amount of nested twisting microcracks without exhibiting catastrophic failure. The development and propagation of these microcracks may be a source of energy dissipation and stress relaxation that ultimately contributes to the remarkable damage resistance properties of the dactyl club.

This study carries out a combined theoretical, experimental, and computational approach to investigate the mechanics and the fracture mechanism of the Bouligand structure. In particular, I study the propagation of a twisting crack that follows the helicoidal arrangement by following the fiber alignment. I carry out specific three-point bending experiments done on biomimetic composite materials and I employ finite element simulations with a 3D cohesive model to simulate the crack growing process. Our study reveals that crack twisting offers additional fracture resistant mechanisms in addition to increasing the effective area of crack growth. Moreover, I develop a theoretical model to provide additional insights into the local stress intensity factors at the crack front of twisting cracks that follows a Bouligand structure. Our results reveal that changes in local fracture mode at the crack front lead to reductions of the local strain energy release rate, hence, increasing the necessary applied energy release rate to propagate the crack and results in the increase in fracture resistance which is quantified by the local toughening factor. Ancillary 3D simulations of the asymptotic crack front field were carried out using a *J*-integral to validate the theoretical values of the energy release rate and the local stress intensity factors. Finally, I design biomimetic helicoidal composites for fiber-reinforced composite materials and perform three different experiments to investigate mechanical responses and performances under dynamic impact, quasi-static uniaxial, and quasi-static biaxial loading. The results show that the biomimetic helicoidal composite has remarkable damage resistance under all loading conditions. These findings provide better understanding on the Bouligand structure which would be initial guidelines to designing composite materials for specific needs in the applications such as armor, automotive, and aerospace.