May 8th, 12:00 AM

Bio Inspired Composites Perform Better In Compression and Impact

Adam Knight
University of Southern Maine, adam.knight@maine.edu

Bio-Inspired Composites Perform Better In Compression and Impact

Adam Knight & Asheesh Lanba

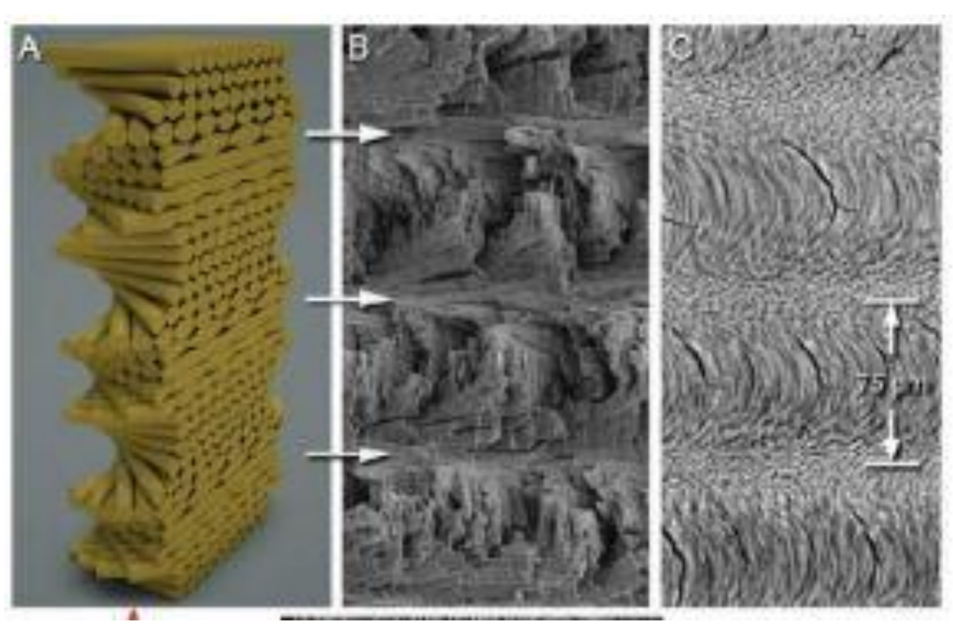
Department of Engineering, University of Southern Maine

LAME LASERS AND MATERIALS ENGINEERING

The various ways that nature has enabled organisms to perform amazing feats is well known. Materials utilized in the construction of biological structures use only what is available, and with the bare minimum of resources, the bodies of some animals outperform advanced materials made by humans. The Peacock Mantis Shrimp uses its dactyl club, creating devastating cavitation bubbles, to obliterate mollusks and other small arthropods on a daily basis. Despite repetitive impacts and cyclic loading in compression, the body parts of the mantis shrimp continue to allow the animal to feed itself. It is now known that the durability of the mantis shrimp is due to the helically structured mineral biopolymer that its shell is composed of, encasing the animal in what is by all definitions an incredibly advanced suit of armor. Helical layup schedules have proven to be more durable in compression and impact testing than traditional layup schedules with uni- or biaxial fiber orientations. In this study, we create a helically stacked laminate composite in ANSYS using a carbon fiber and epoxy pre-preg (CFRP) material. Tsai-Hill and Tsai-Wu failure criterion for composite laminate are used to determine failure. We perform compression and point force analysis on this composite material and compare its performance to composites commonly used in industry. Composite structures employed in daily industrial applications frequently sustain impact damage; these loadings are constantly present in real world composite employment and frequently result in damage emerging as micro-cracking in the polymer matrix and/or fracture of the fiber tows of the reinforcement.

Peacock Mantis Shrimp

Biomineral Helical Structure of the Mantis Shrimp Dactyl Club



Helical Layup Schedule, Top Down:

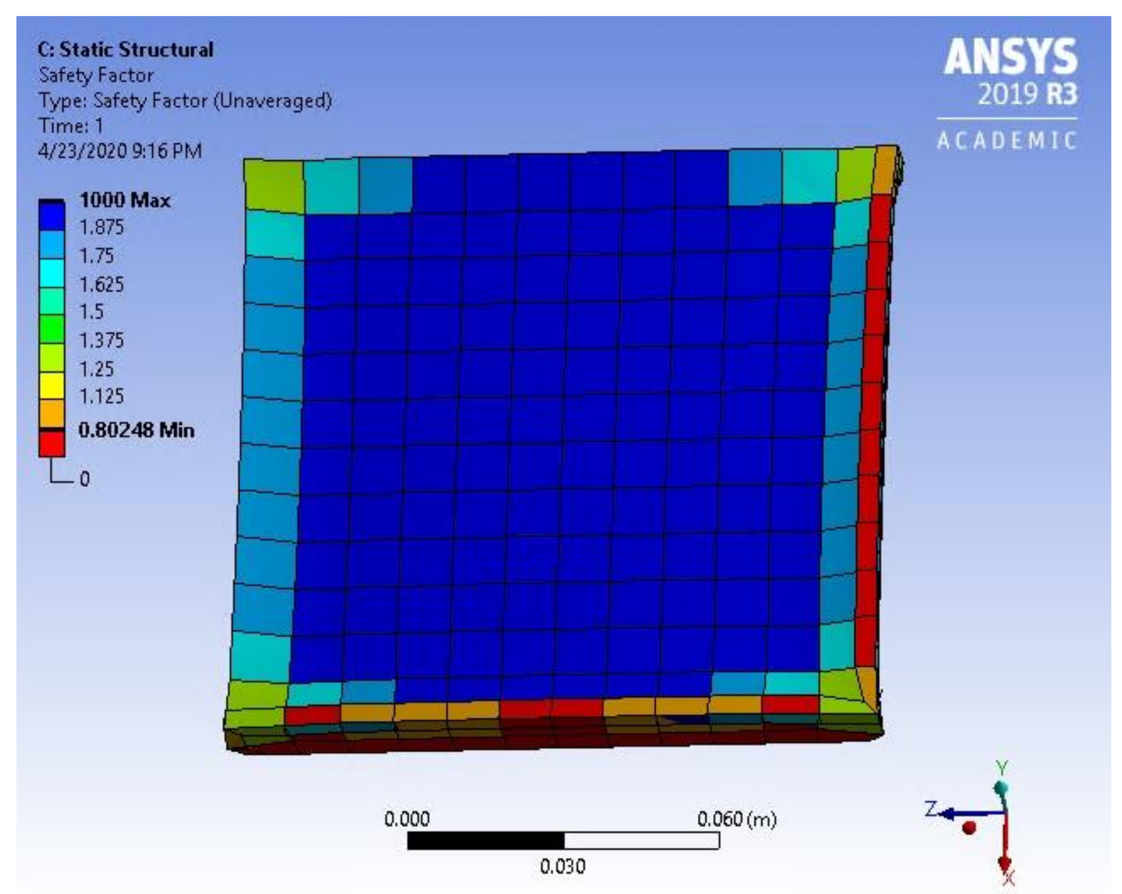
Layer	Fabric	Angle
1	Carbon Fiber	360
2	Carbon Fiber	288
3	Carbon Fiber	216
4	Carbon Fiber	144
5	Carbon Fiber	72
6	Carbon Fiber	0
7	Carbon Fiber	72
8	Carbon Fiber	144
9	Carbon Fiber	216
10	Carbon Fiber	288
11	Carbon Fiber	360

Laminate Model Parameters:

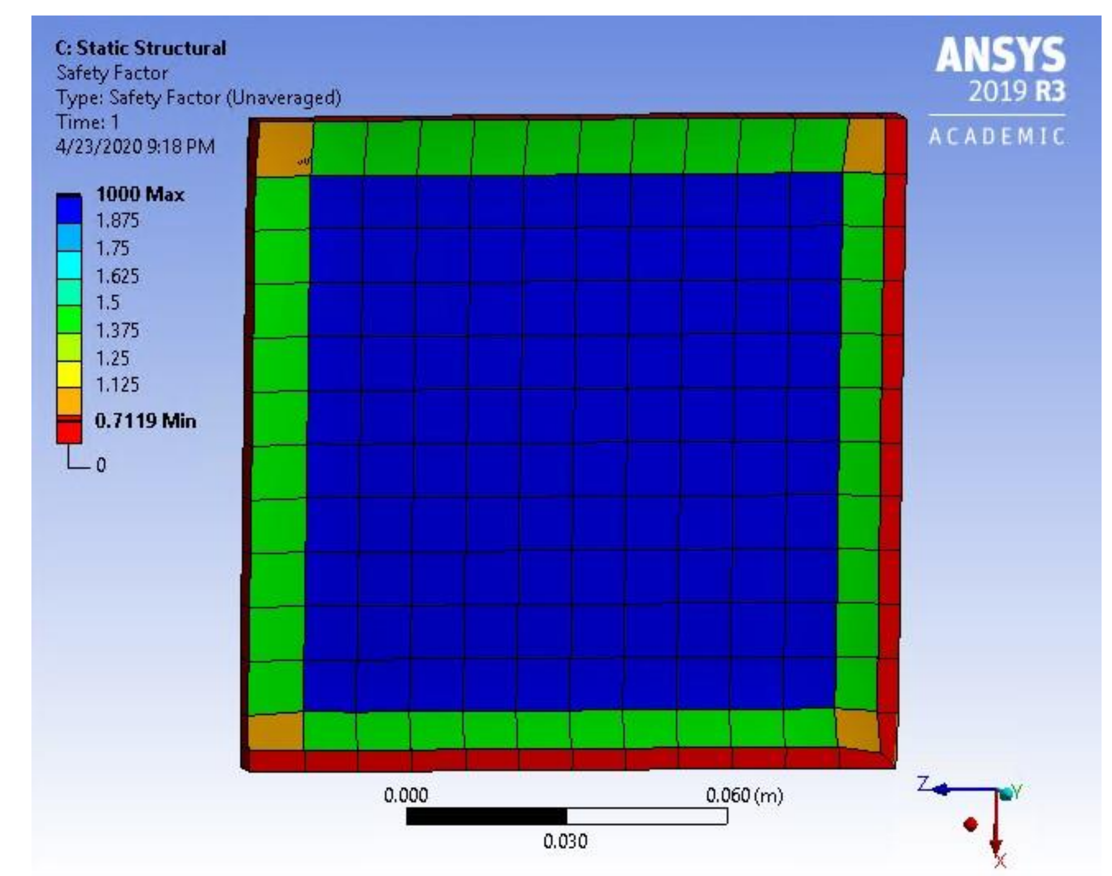
- 11 plies of CFRP rotated 72 degrees per ply
- 4.4 mm thick
- Compared to a standard 0°/90 ° CFRP
- CPRP material data provided by ANSYS

Compression Testing w/in ANSYS Mechanical, 1 GPa load

0°/90° Laminate

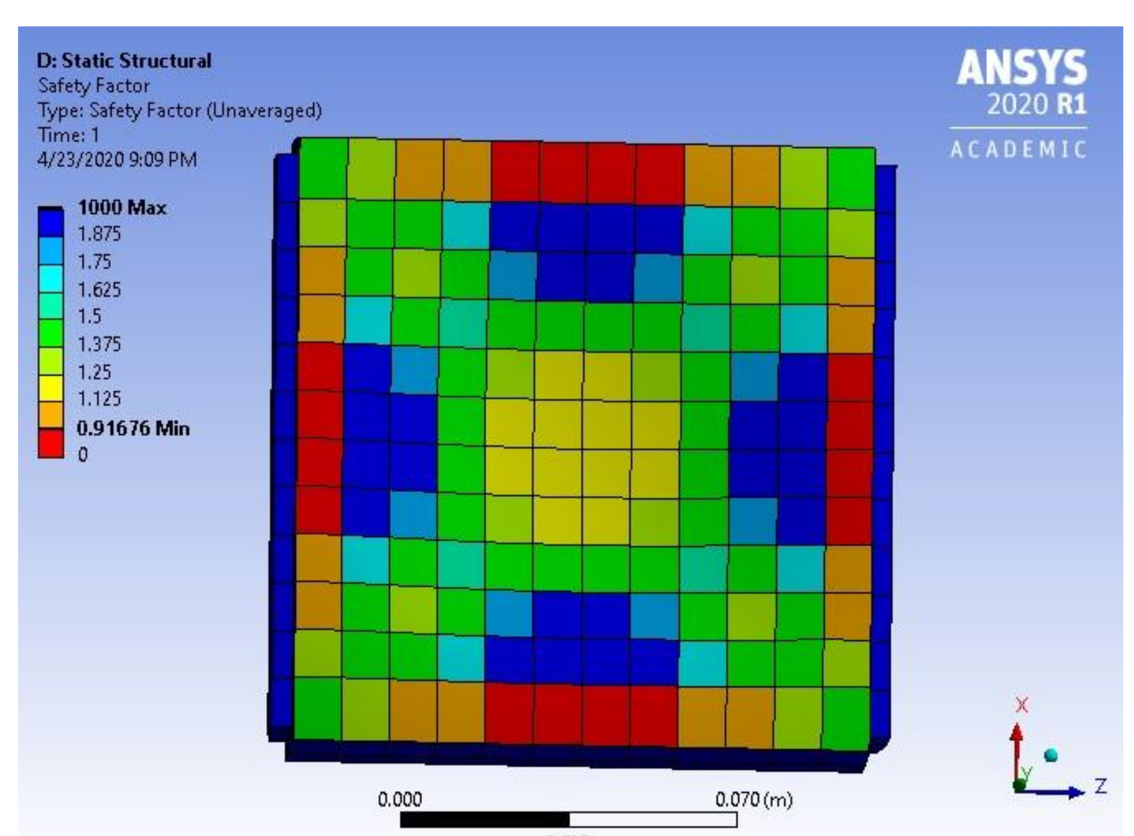


Helical Laminate

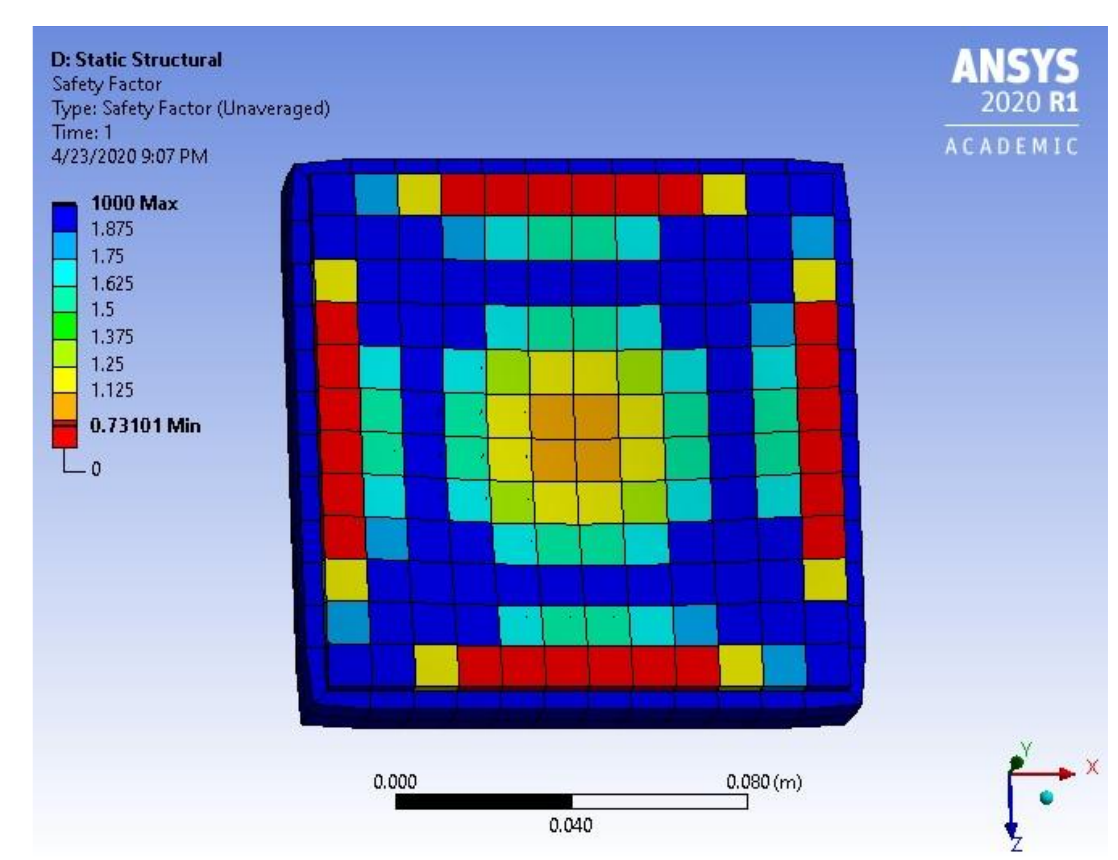


Point Force Testing w/in ANSYS Mechanical, 50 kPa load

0°/90° Laminate



Helical Laminate



For image above, regions w/ a safety factor less than one (red) have experienced failure according to the Tsai-Hill and/or Tsai-Wu criterion

Tsai-Hill Criterion of Composite Failure

- Based on modifications of yield criteria for metals, the Tsai-Hill Criterion defines composite failure stresses since composites are transversely isotropic

$$\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix} = [T] \begin{bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{bmatrix}$$

$$\left(\frac{\sigma_1}{\sigma_{1u}}\right)^2 + \left(\frac{\sigma_2}{\sigma_{2u}}\right)^2 - \frac{\sigma_1 \sigma_2}{\sigma^2{}_{1u}} + \left(\frac{\tau_{12}}{\tau_{12u}}\right)^2 = 1$$

Conclusions

- Helically laid-up laminate behaves more like a homogenous, isotropic material, providing not only better mechanical properties in compression, but also displays a significant reduction in deformation when compared to a standard 0°/90° laminate.
- Helical laminate lay-ups perform significantly better when subjected to a point load, distributing stress in a more preferable manner, and allowing less deflection of the substrate.

References:

Cambrige University 2020

Bio-Inspired Impact-Resistant Composites Grunenfelder, 2014

Crustacean-Inspired Helicoidal Laminates Shang, 2015

Biomechanical Design of the Mantis Shrimp Saddle Tadyon, 2018

The Stomatopod Dactyl Club Weaver, 2012

Acknowledgements:

Special thanks to the LAME group for supporting this project and making this presentation possible.