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Finite Element Analysis of Impact Resistant Composites Inspired by Peacock Mantis Shrimp

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The fist-like club of the peacock mantis shrimp, a 5-inch marine crustacean, can strike its prey with a speed faster than a .22-caliber bullet with an impact force more than 1,000 times its own weight. Although these creatures punch so fast that it even boils the water, they don't take any damage. This incredible insusceptibility is due to the arrangement of mineralized fiber layers in which each fibrous layer is laid at a slightly rotated angle to form a helicoidal structure which acts as a shock absorber for the club. The goal is to perform a finite element analysis to investigate the impact resistance and failure mechanism of the helicoidal stacking found in the club and compare it against the conventional unidirectional and quasi-isotropic structures.

Introduction

Past studies have proven the durability of helicoidal architecture under compression and during impact testing as compared to conventional composite layups. We compare the performance of two helicoidal setups – one with an angle of 7.2 degrees and the other with an angle of 16.4 degrees – against unidirectional and quasi-isotropic samples. Modelling and analysis will be performed on ANSYS on panels made of carbon fiber epoxy prepreg with a unidirectional reinforcement.

Finite Element Analysis Using ANSYS

- Panel dimension: 100 mm X 150 mm
- 52 plies of Carbon fiber epoxy prepreg
- 7.02 mm thickness
- Load applied: 25 kN
- Velocity of bullet: 100 m/s
- Failure Criteria Used:
  - Maximum stress
  - Maximum strain
  - Tsai-Hill
  - Puck

Composite Layup

Sample	Layup
Small angle helicoid	[0/7.2/14.4/…/180]
Large angle helicoid	[0/16.4/32.8/…/180]
Unidirectional	[0]
Quasi-isotropic	[0/90/+45/-45]

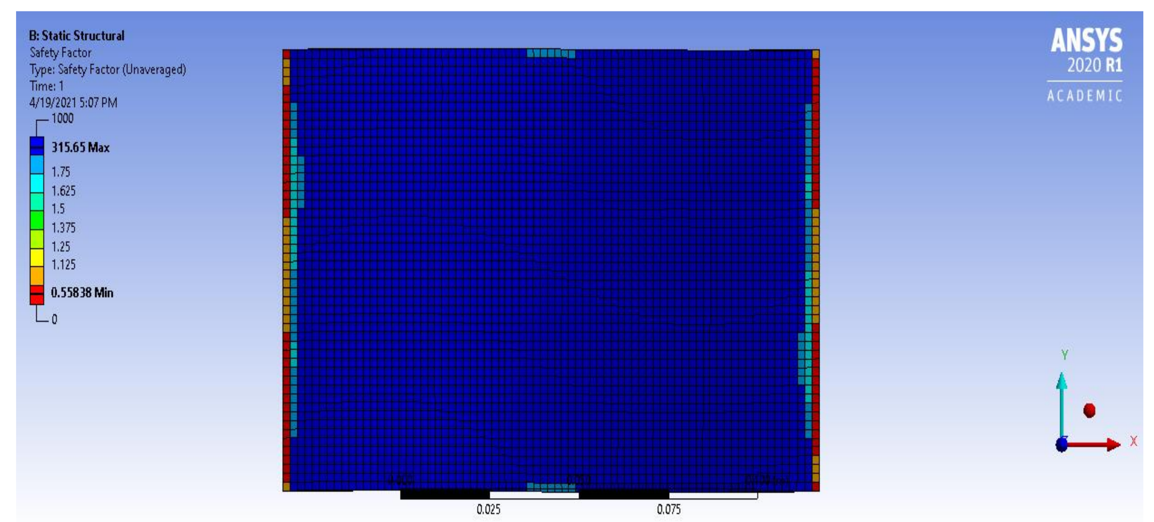

Figure 1: 7.2-degree helicoidal architecture

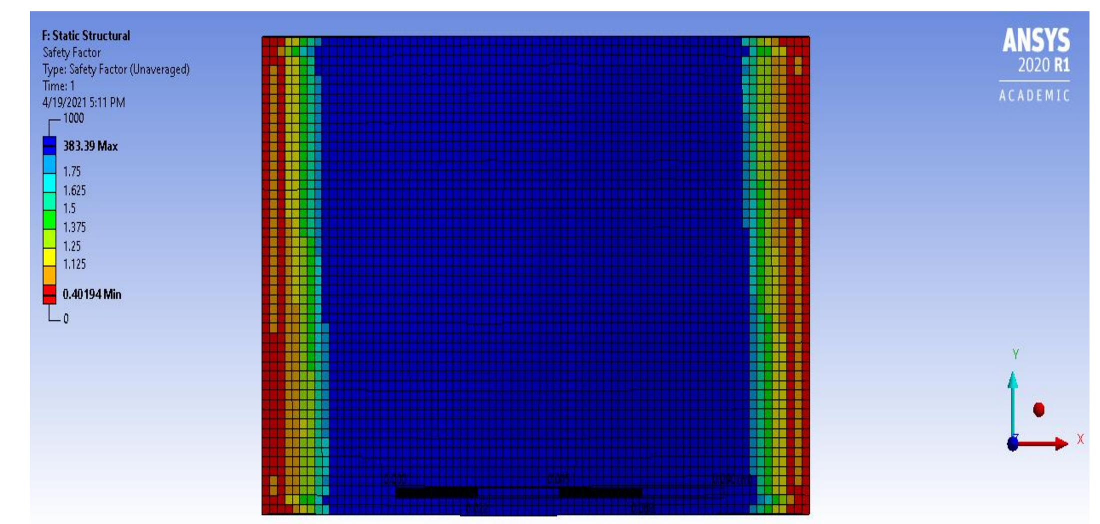

Figure 2: 16.4-degree helicoidal architecture

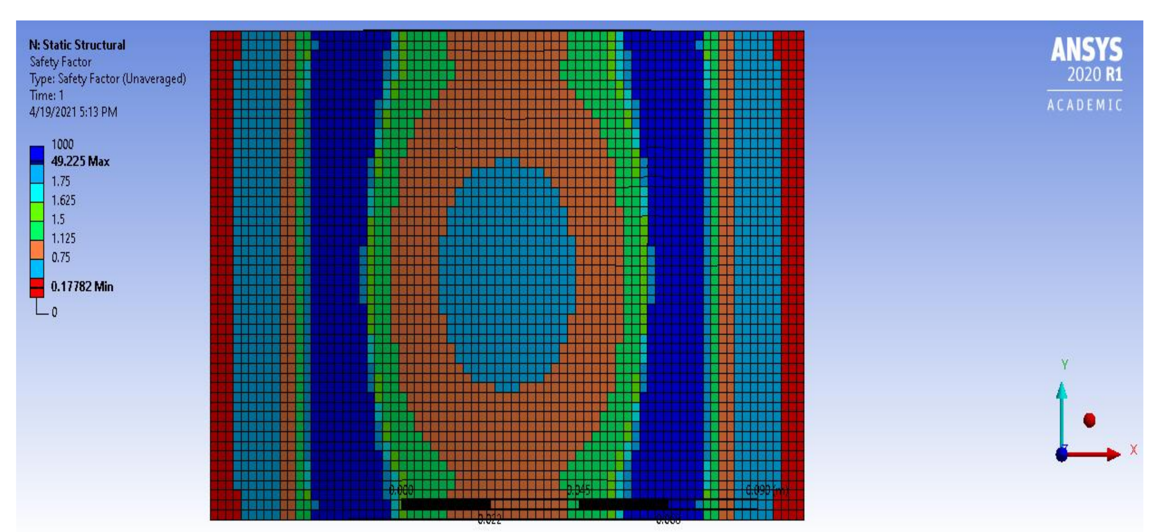

Figure 3: Unidirectional composite setup

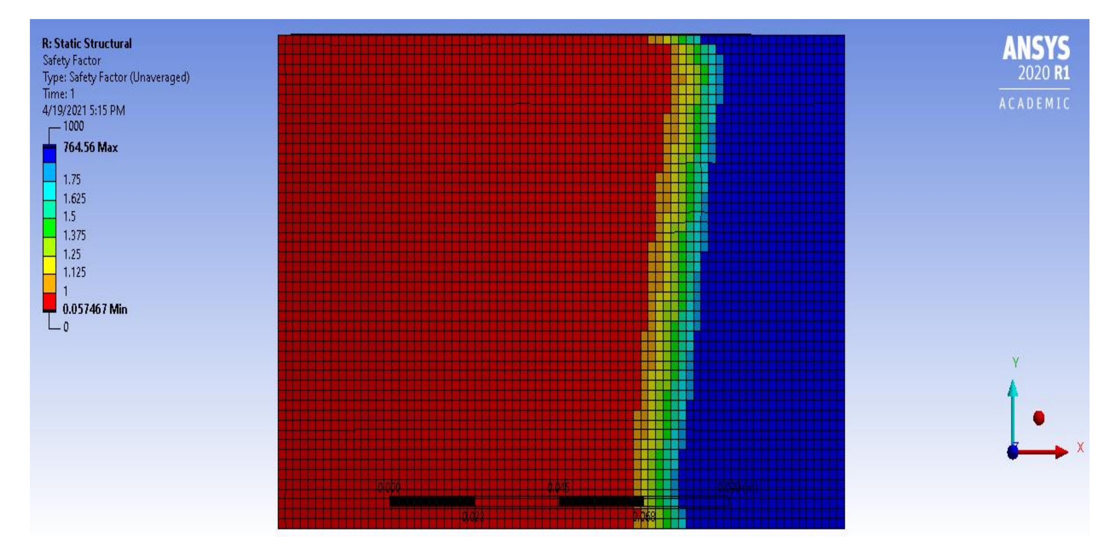

Figure 4: Quasi-isotropic composite layup

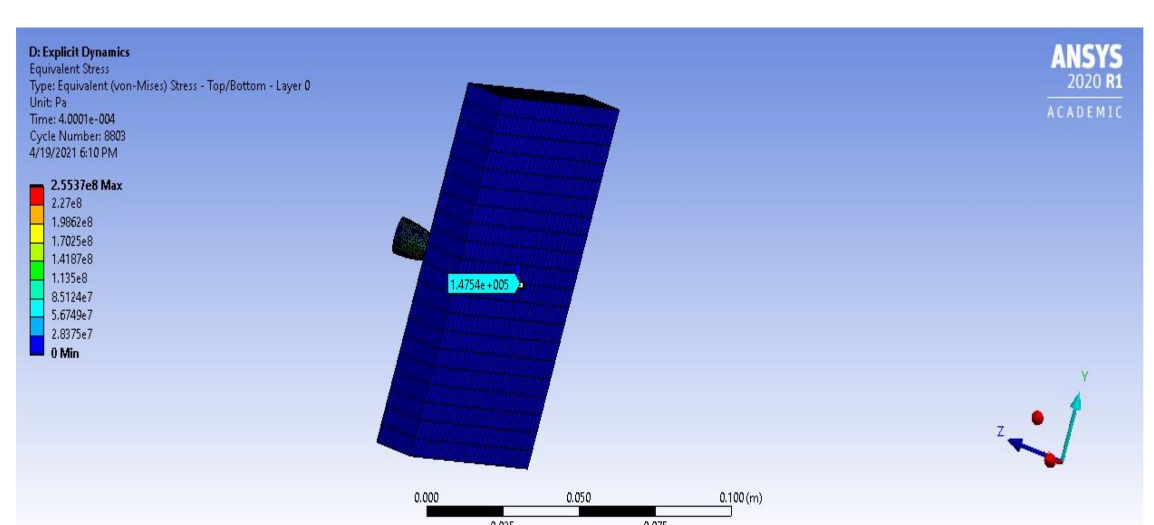

Figure 5: Bullet penetration in a 7.2-degree helical stack up

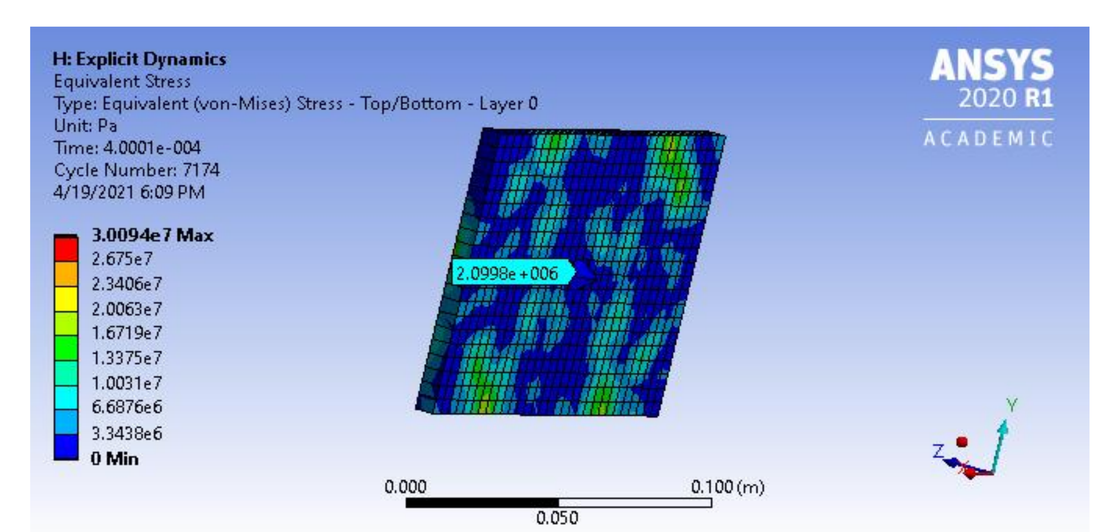

Figure 6: Bullet penetration in a 16.4-degree helical stack up

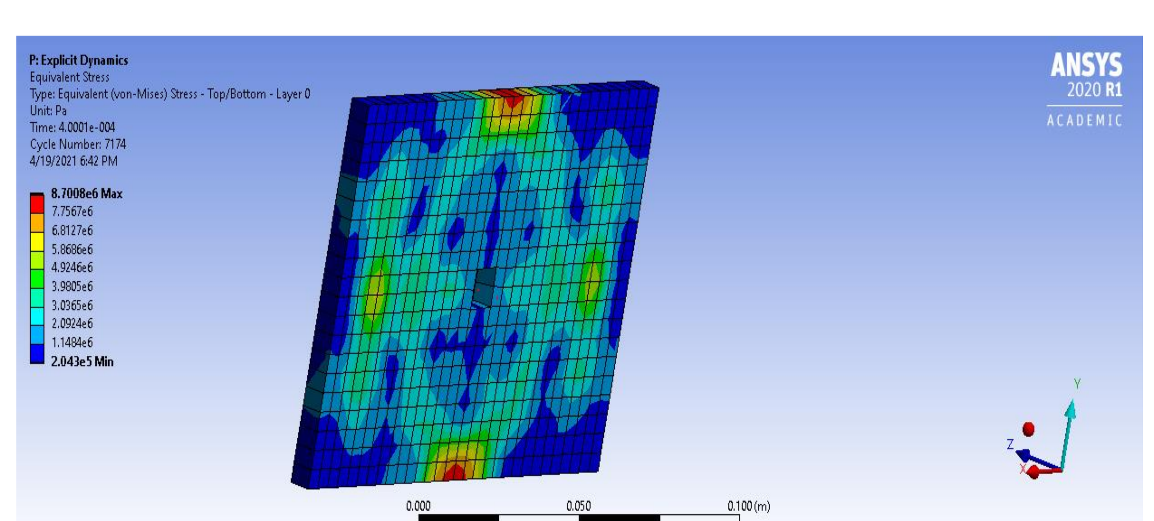

Figure 7: Bullet penetration in a unidirectional stack up

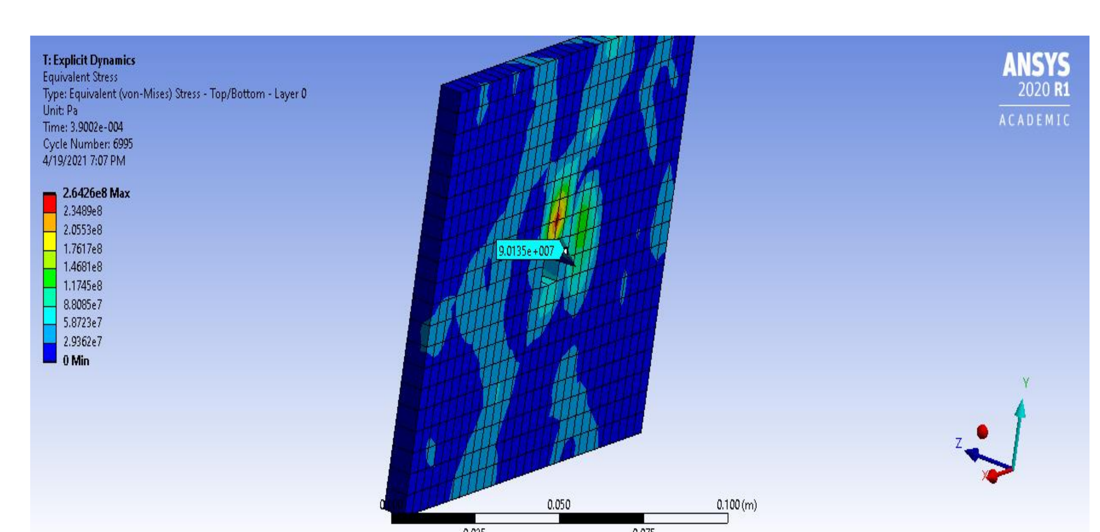

Figure 8: Bullet penetration in a quasi-isotropic stack up

Conclusions

- For static loading, smaller angle helicoidal stack up (Figure 1) performs much better than any other composite layups. In figures 1 through 4, red boxes denote factor of safety less than 1. Helicoidal architectures are more durable than the two sample structures, more than half of the quasi-isotropic structure fails.
- Similarly, for dynamic analysis, while the bullet does not penetrate through either helicoidal stackups (Figure 5 & 6), both the sample structures (Figure 7 & 8) fail upon impact.

Future Work

The helicoidal architecture inspired by mantis shrimp could be tested as body armors, helmets, shields for spacecrafts, and aircraft parts.

Acknowledgments

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Literature cited

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