Foldcore Sandwich Structures for Hypervelocity Impact Energy Absorption Applications under Cold Temperatures

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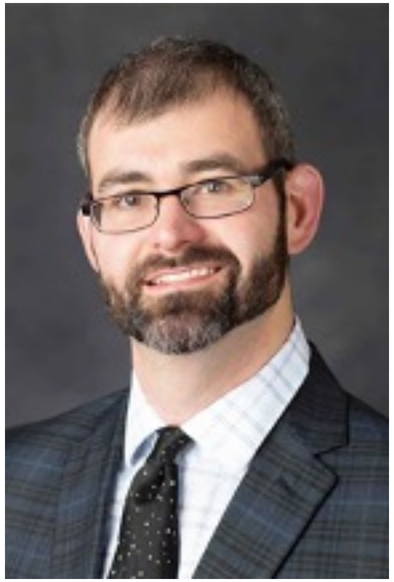

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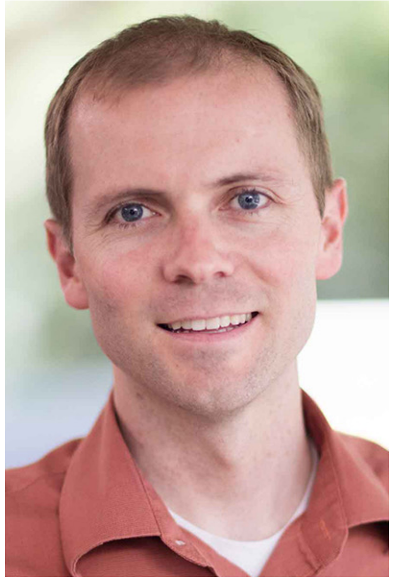

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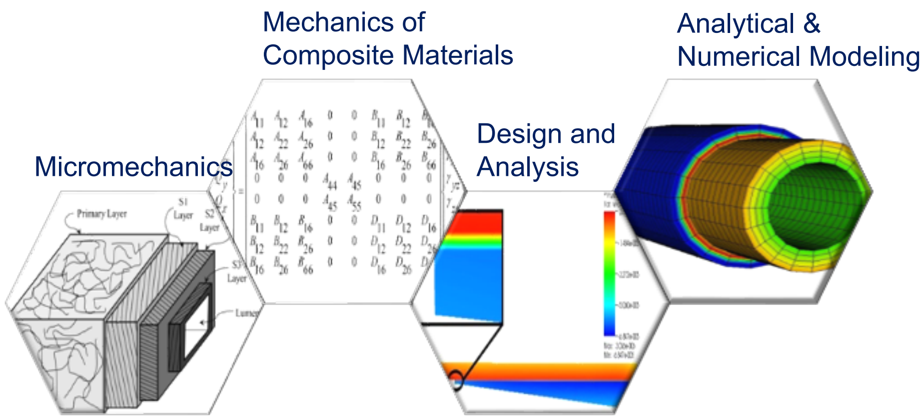
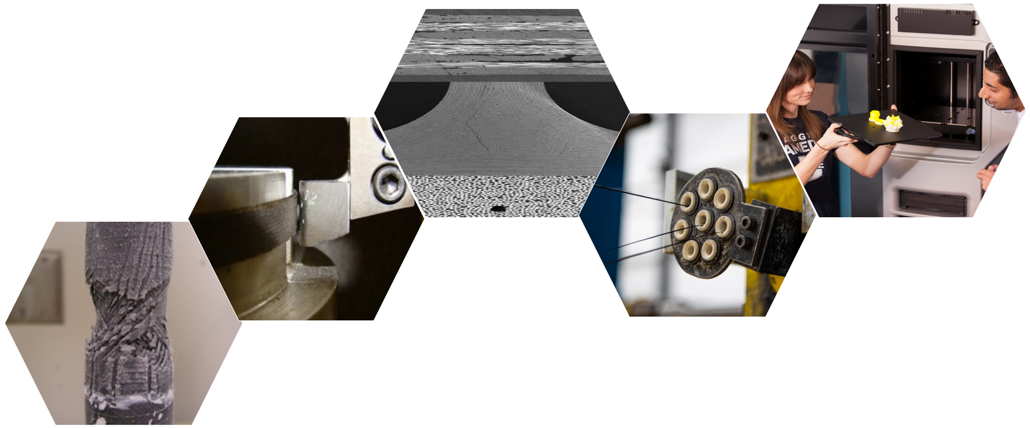
USU Composites Research

Center for Manufacturing & Design of Advanced Materials

- MS in Composite Materials & Structures (USU/WSU joint graduate program)
- **Objective:** To provide a structure for education and research to improve the design and processing of advanced materials in the industries in the state of Utah
- **Outcomes:** Increased number of prepared students to enter industries in the state. Improved manufacturing techniques through research.





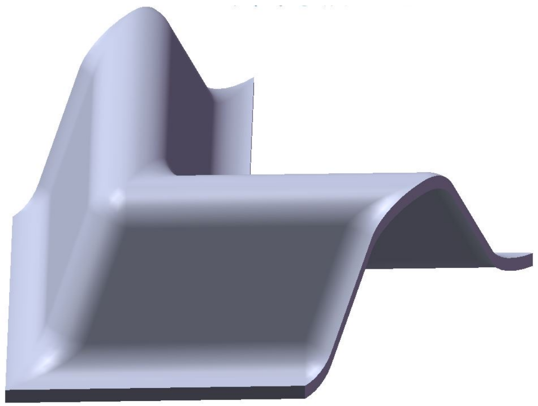
Foldcore – Background

A foldcore is an alternative core material made of thin carbon or glass fiber laminates folded in an origami pattern, providing tunable structural performance.

Foldcore Sandwich Composites (FSCs) have the following potential advantages over legacy core materials:

- Open channels for moisture evacuation and heat transfer
- Optimizable unit cell geometry
- Redirection of impact debris
- Core material is stronger than paper honeycomb or foam

The tunable nature of a foldcore design provides versatility and application-specific properties.



Foldcore unit cell
(Miura-folding)

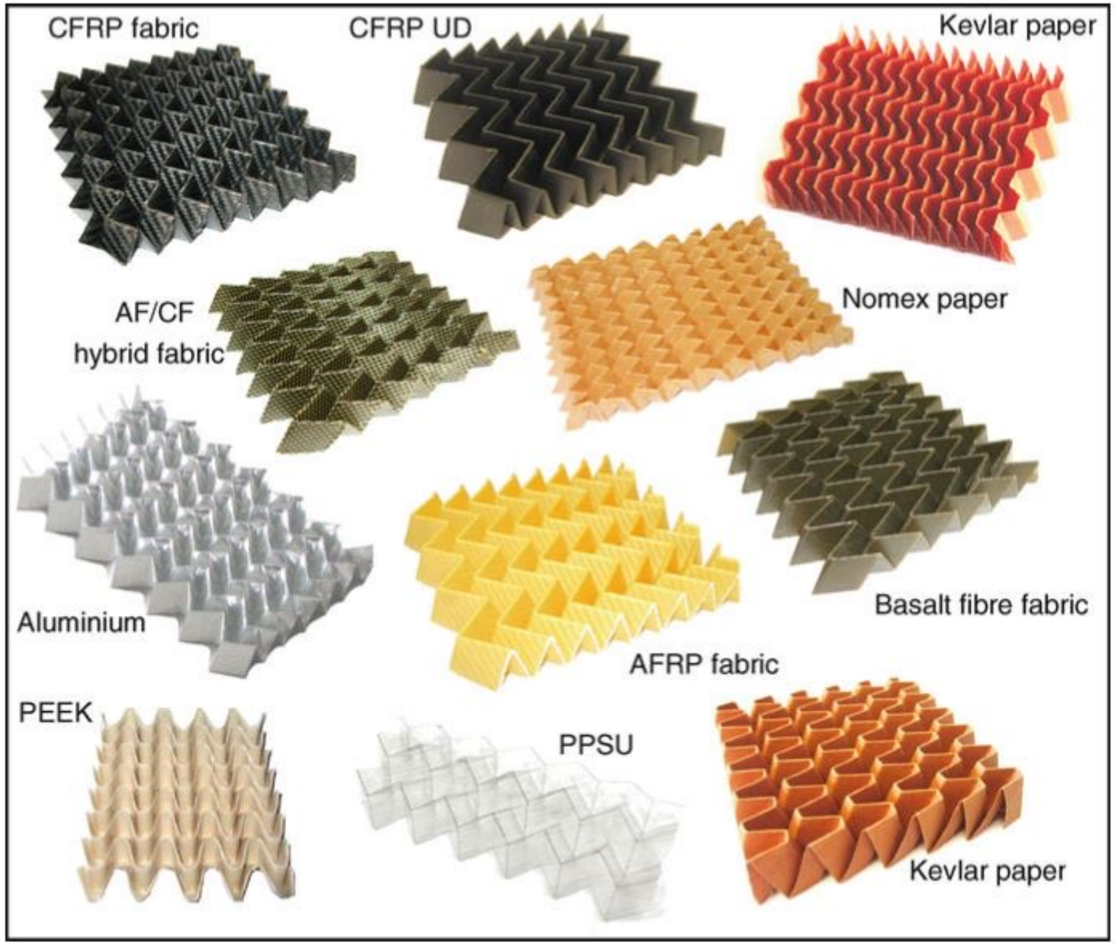
Foldcore – Background

Substantial work has been done on foldcore research since the 1990's.

Foldcores have been manufactured with various materials and shapes. Papers have been published on the following mechanical tests.

- Compression/Shear
- Bending & Skin Debonding
- Low-High Velocity Impacts

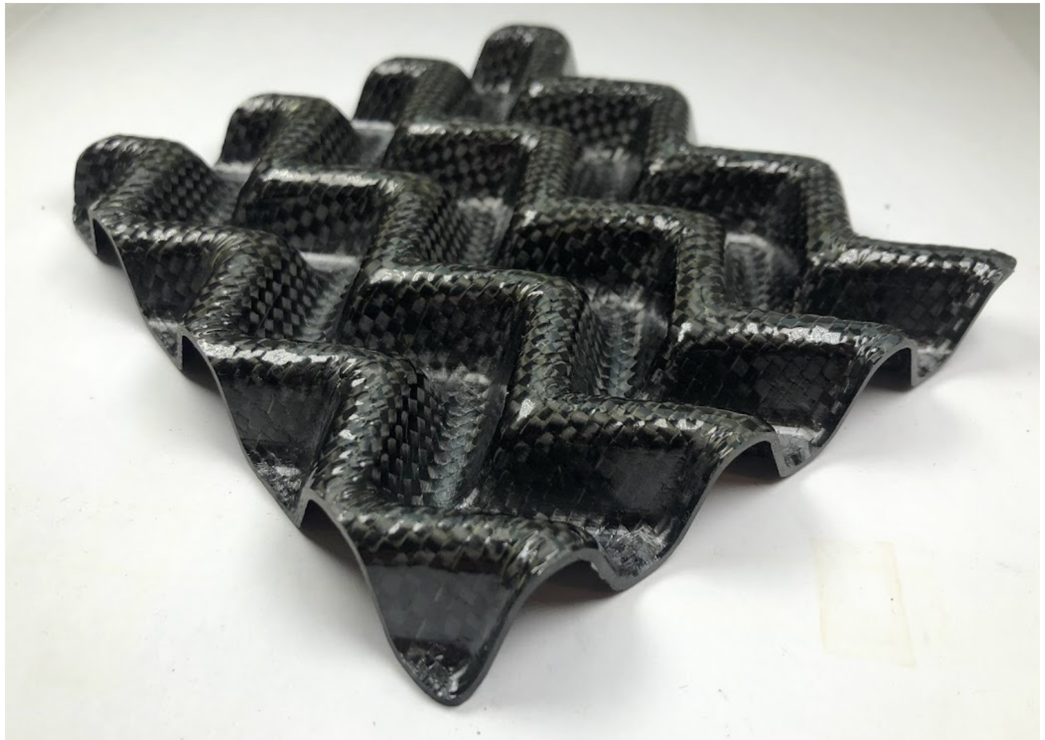
Potential applications include, aircraft fuselages, control surfaces, marine structures as protective armor for military and space systems.



Heimbs (2012), DFCSS, 491–544.

Foldcore Manufacturing

USU started preliminary study in Fall 2021 and secures FSC manufacturing capability early 2022

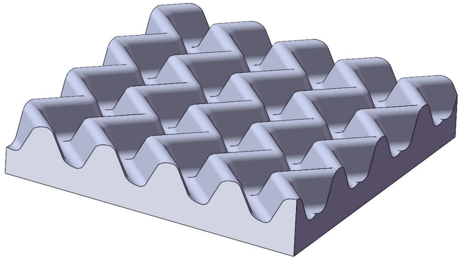


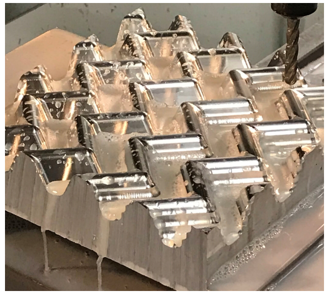
CFRP Foldcore

- Miura-folding
- 5” x 5” x 0.7” (t = 0.06”)
- Miura-folding pattern
- 8 woven carbon/epoxy prepregs.
  - Hexcel AS4 3k PW CF fabric
  - 3501-6 epoxy resin

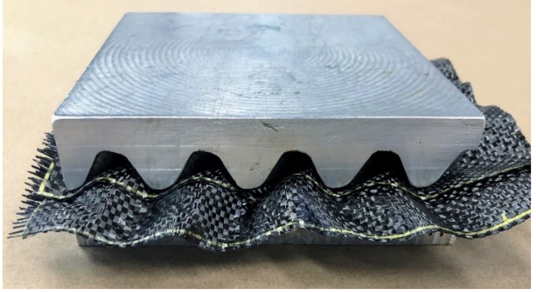
WF prepregs shows better formability than UD one.

FSC Manufacturing





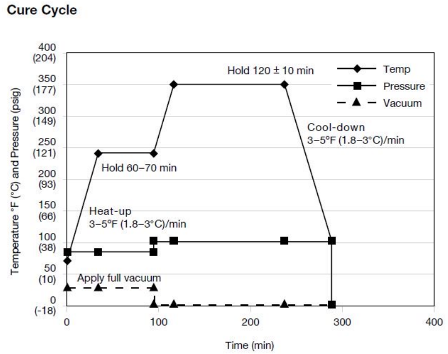
Mold fabrication



Pre-folding

Lay-up & bagging

Cure

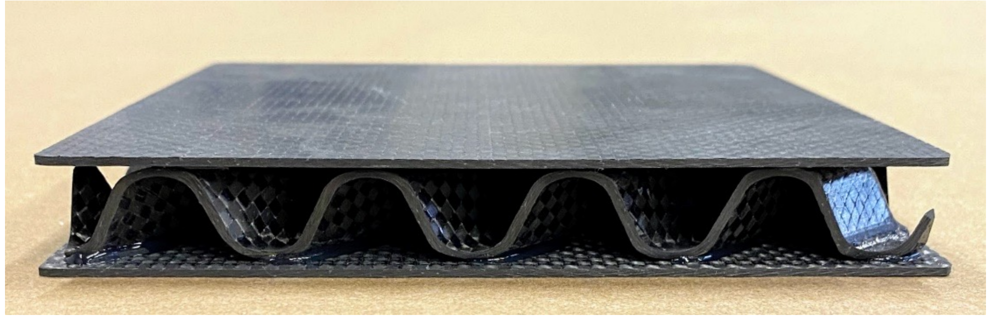


CFRP Foldcore

(90°)

Open Channel (0°)

CFRP FSC



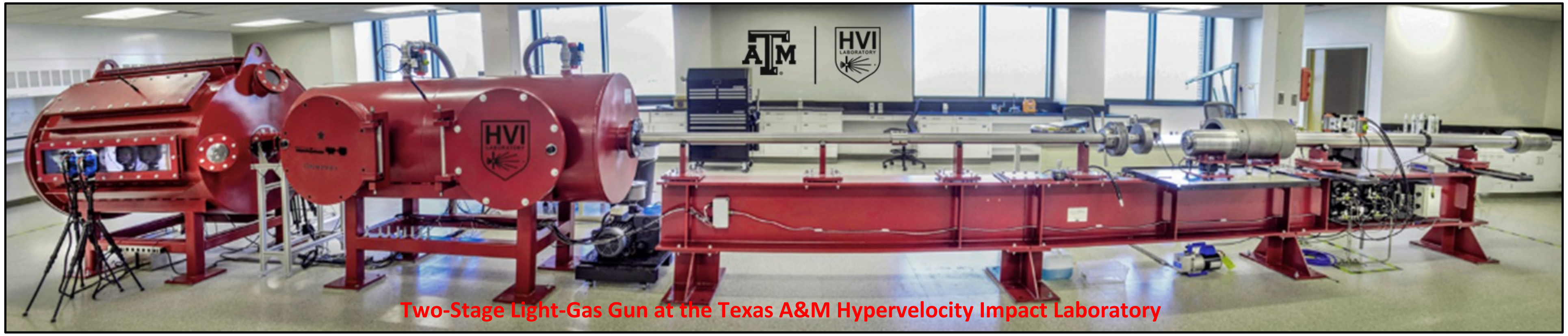
Foldcore and skin panels are bonded with 3M DP420 epoxy adhesive.

Hypervelocity Impact Tests

USU collaborates with TAMU Hypervelocity Impact Lab for “development and tailoring of novel structures comprised of advanced materials, including metals, composites, polymers, ceramics, and geomaterials.”

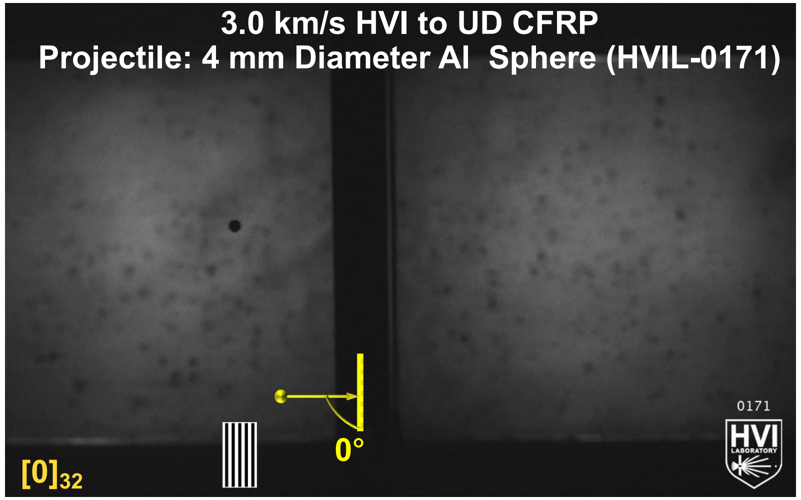
A series of HVI tests are performed:

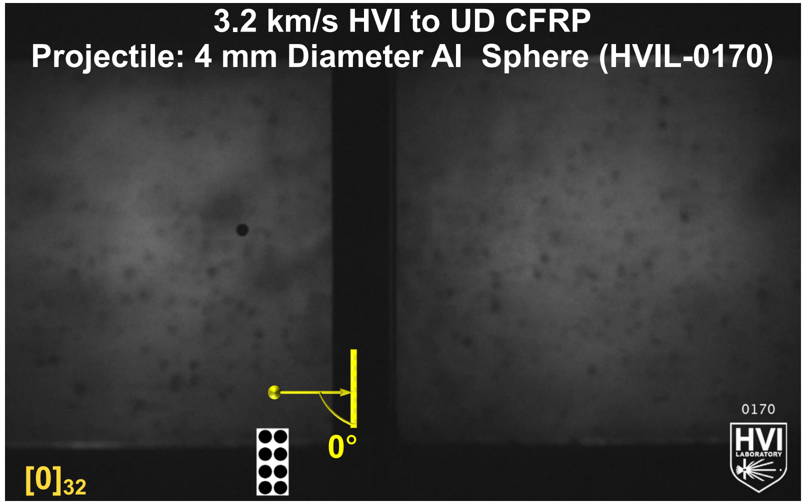
- on flat CFRP panels with various layups (CHECK anisotropic failure).
- on CFRP FSCs with different opening channels (CHECK fragments redirections).
- at 3 km/s normal (0°) and oblique (45°) impact (CHECK fragments expansion).

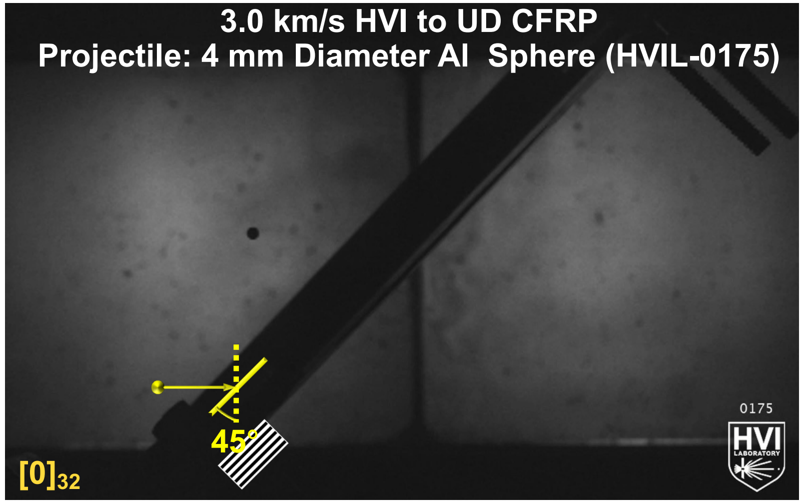


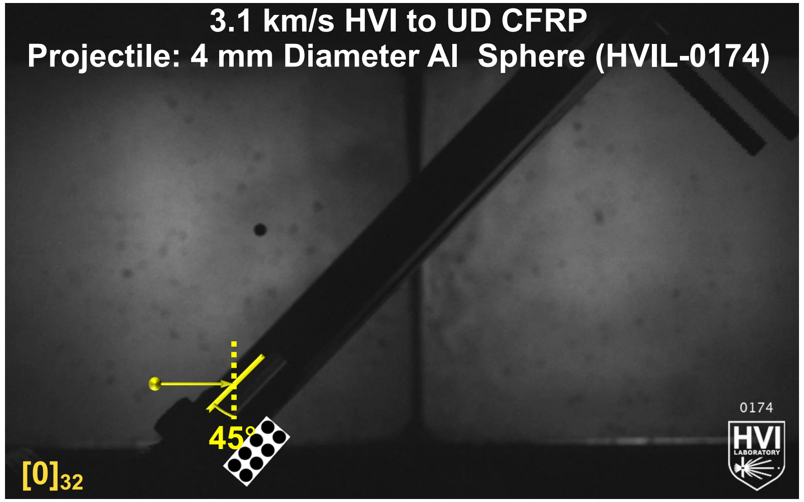
Two-Stage Light-Gas Gun at the Texas A&M Hypervelocity Impact Laboratory

HVI Testing on Flat CFRP Panels





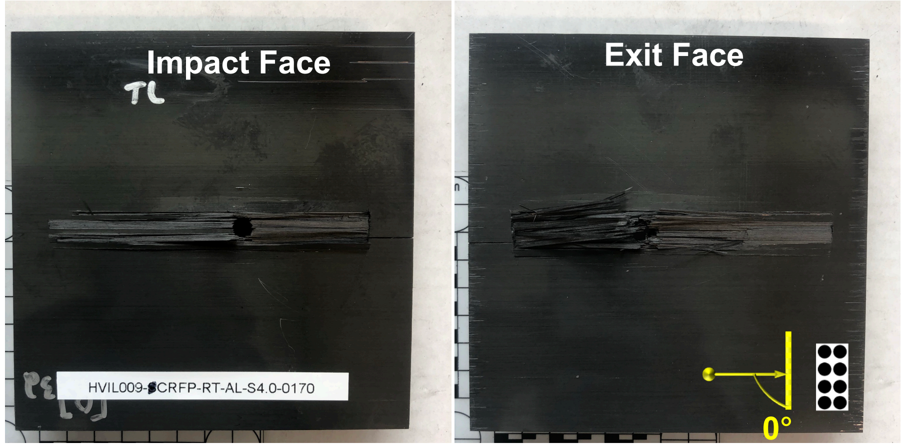




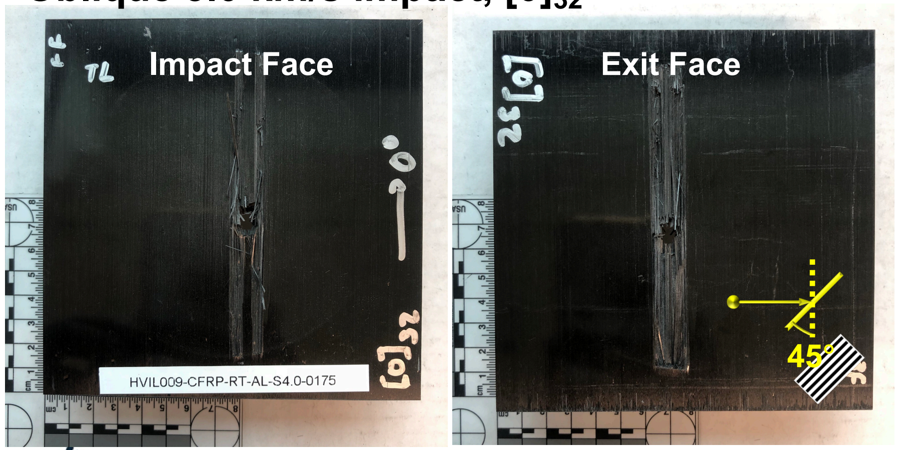
HVI Testing on Flat CFRP Panels

Normal 3.0 km/s impact, $[0]_{32}$

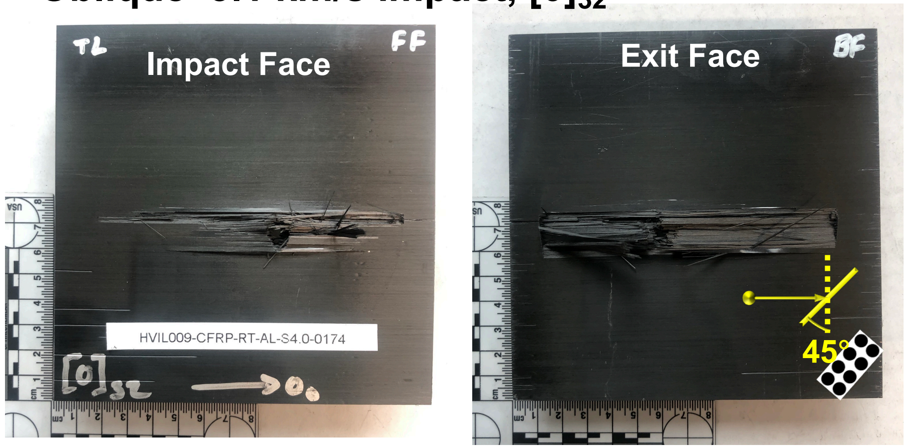
Normal 3.2 km/s impact, $[0]_{32}$



Oblique 3.0 km/s impact, $[0]_{32}$



Oblique 3.1 km/s impact, $[0]_{32}$



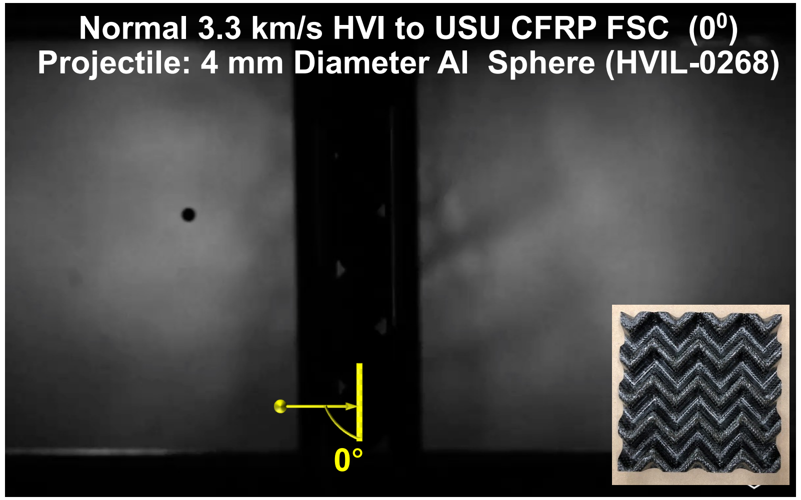
Key Findings:
Fragment cloud expansion and structure damage are governed by:

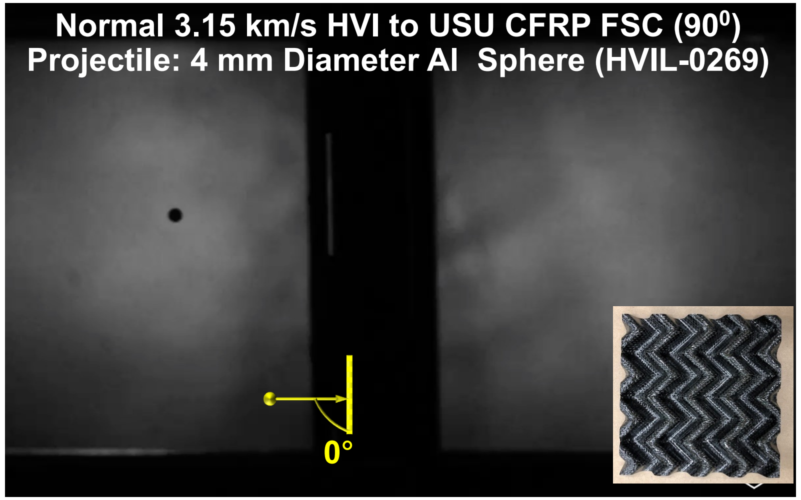
- Lay-up
- Impact angle

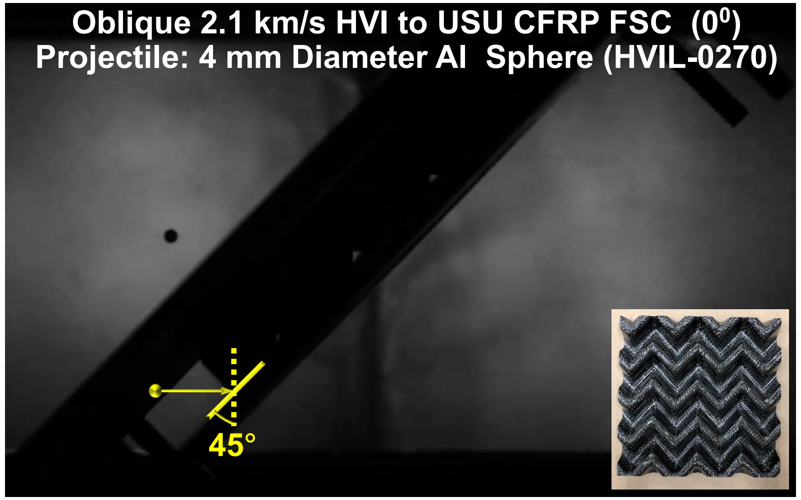
This suggests that composite lay-up and impact angle are design factors that can optimize HVI mitigation.

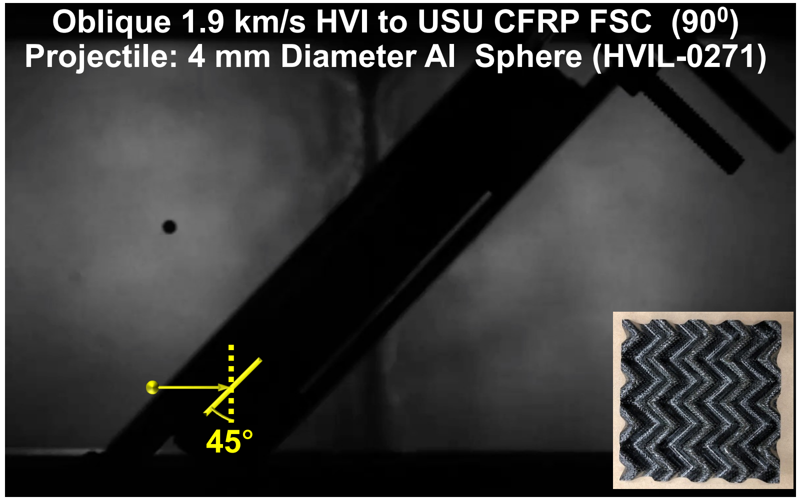
These can be easily tuned in FSCs!!

HVI Testing on CFRP FSCs









Validation:
Fragment cloud expansion and structure damage are very different for flat and FSC CFRPs

Foldcore configurations (i.e., material, layup, folding pattern, type) can be optimized for the maximum HIV resistance.

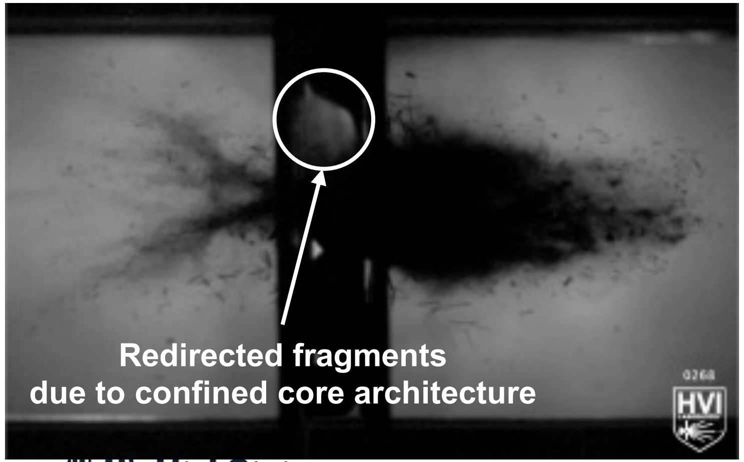
Typical honeycomb & polymer sandwich panels have *limited* design variables.

Why FSC Performs Better?

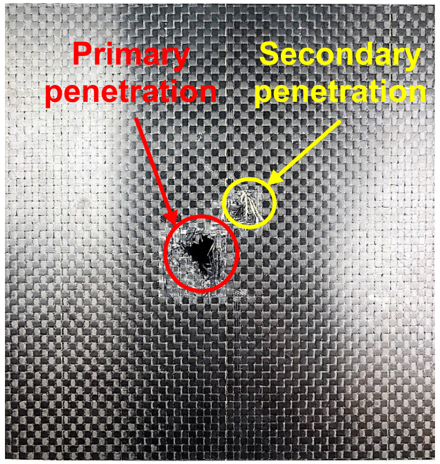
FSC has several open channels. Each of open channel creates internal bumper and redirects fragments inside the foldcore, creating less back-face fragment cloud expansion and smaller exit hole, i.e., the Whipple shield for spacecraft protection.

Prototype FSC under normal impact (left) shows two exit holes, suggesting the potential controllability of a projectile. *Ideally*, optimal FSC can capture/hold an incoming projectile.

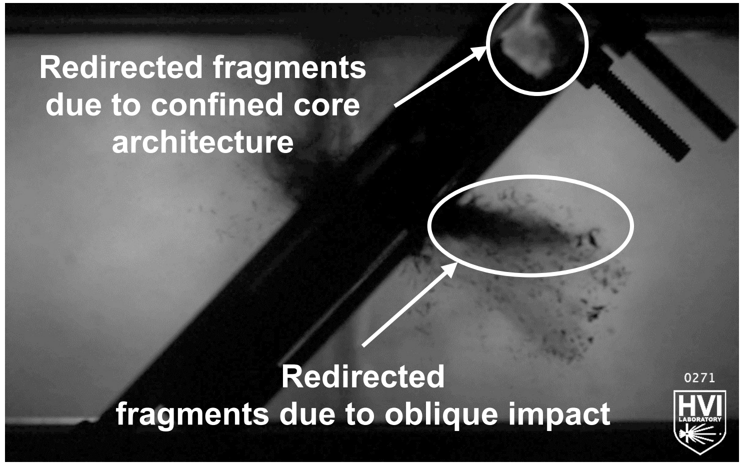
Fragments Cloud Expansion



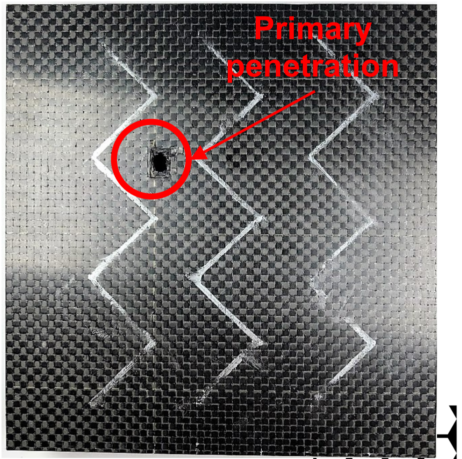
Back-face Damage



Fragments Cloud Expansion



Back-face Damage

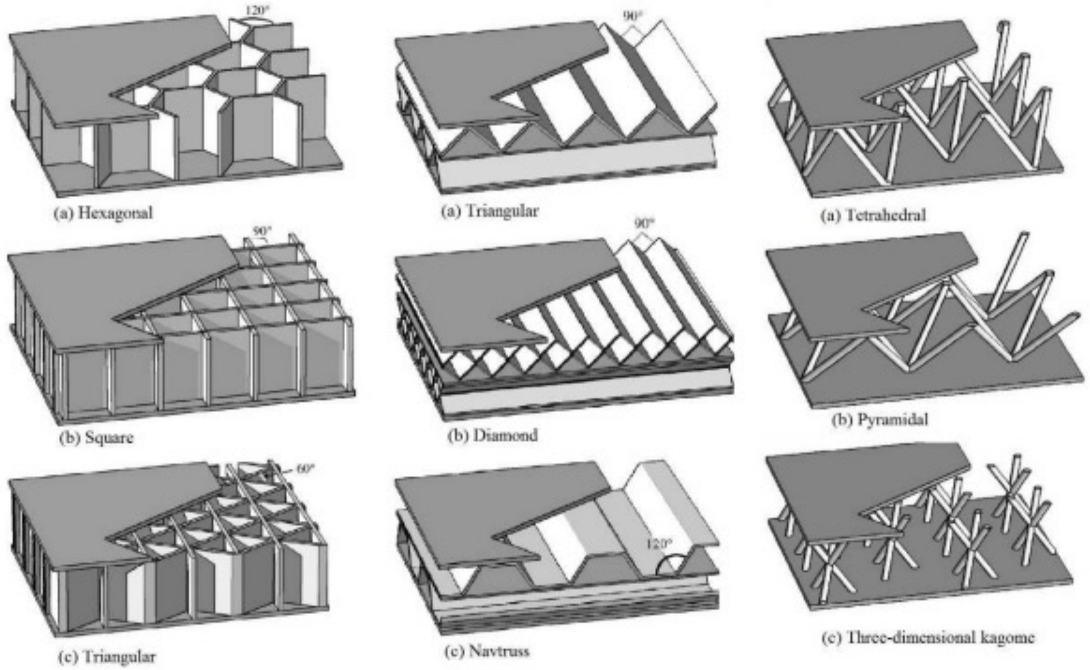


FSC Design Variables – Core Topologies

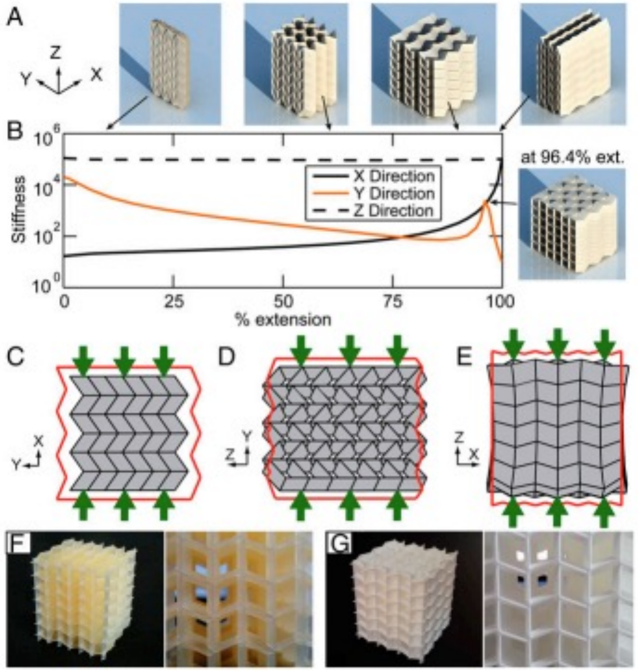
FSC performance can be easily tailored to given design requirements/constraints.

Geometric Variables:

- Folding pattern, unit-cell geometry, stacking pattern/sequence, etc.



Wadley (2006), Philos. Trans. R. Soc. A, 31-68.



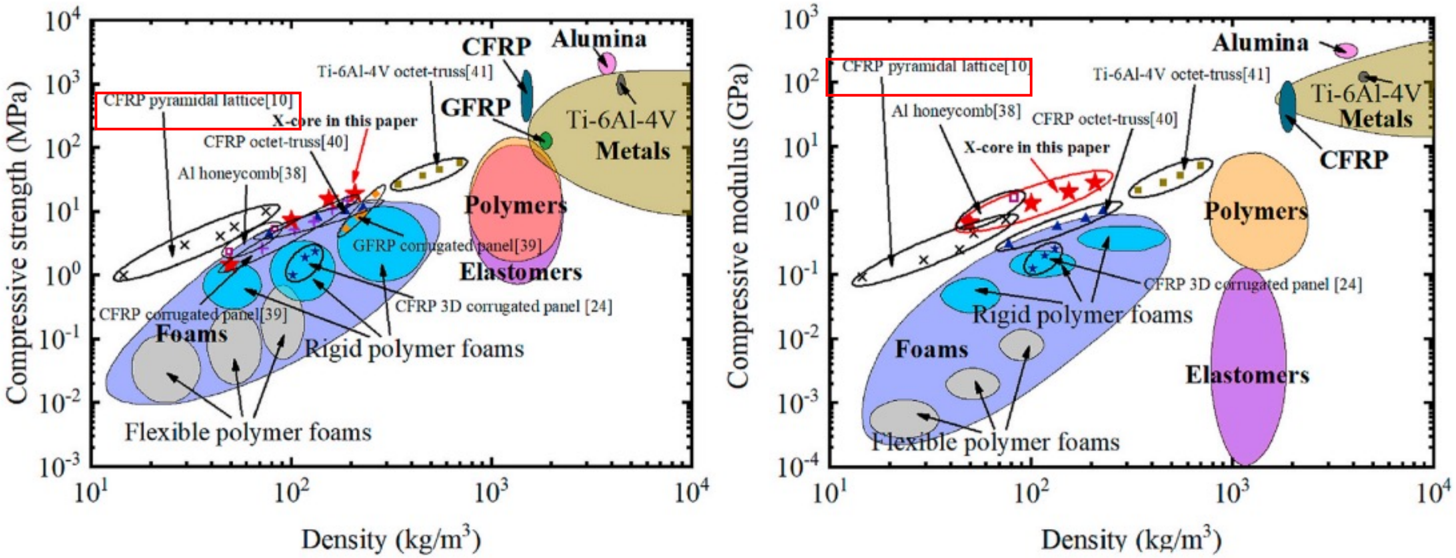
Filipov, Tachi, & Paulino (2015), PNAS, 12321–12326.

FSC Design Variables – Materials

Material Variables:

- A sheet of single or multi-layered materials can be folded in any shapes.
  - Aluminum, CFRP, GFRP, Aramid, Kevlar, Basalt, PEEK, etc.
  - Multi-layered hybrid foldcores often manufactured for multifunctionalities.
  - Manufacturability: prepregs >> dry fabrics

- Use of stiffer materials requires aggressive manufacturing process.



Mei et al (2021), TWST, 107144

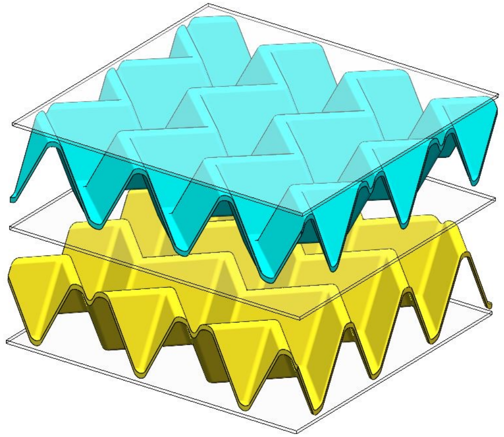
FSC at Extreme Environments

Significance of the Problem:

- Conventional foam cores have issues on limited geometric design variables to improve energy absorption, expensive manufacturing, and moisture/fluid accumulation.
- Sandwich structures may not perform well at extreme environments (i.e., temperature and water flow.
- Performance are hardly tailorable.

Opportunities:

- FSCs can be easily manufactured to have superior mechanical performance and several multifunctionalities (it is integrated structure) by:
  - ➢ Core topology optimization
  - ➢ Appropriate core material selection



USU FSC Research

Goals:

- The research is aimed at designing, testing, characterizing, and multiscale modeling novel lightweight FSCs, including both cores and face sheets to improve their HVI mitigation.
- The present work primarily focuses on characterizing the highly nonlinear dynamic HVI responses of FSCs with various origami-inspired core configurations (folding pattern, core dimensions, etc.) at low (-50°C), room, high (50~100°C) temperatures.

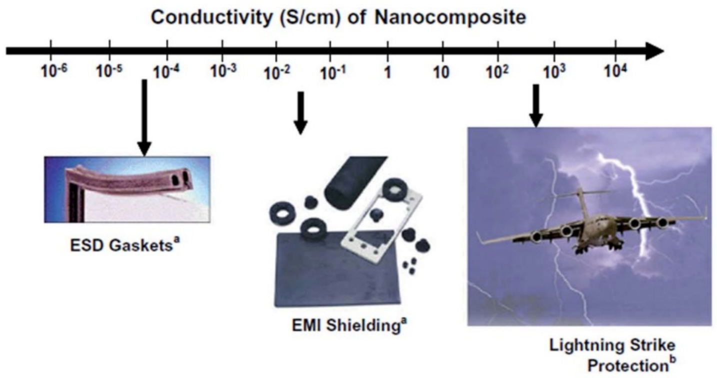
Objectives:

- To manufacture novel FSCs with tunable high energy impact resistance performance at various temperatures providing baseline data for future integrated research.
- To create a solid pipeline for USU students to work on "practical" research relevant to aerospace defense manufacturing.

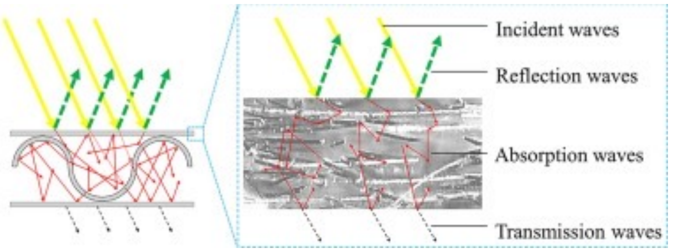
Current Status: RT HVI tests (done); low/high temp HVI tests (*proposed ideas*).

Potential Applications

Multifunctional structural panel with EMI/Lightning protection



www.chomerics.com & www.boeing.com

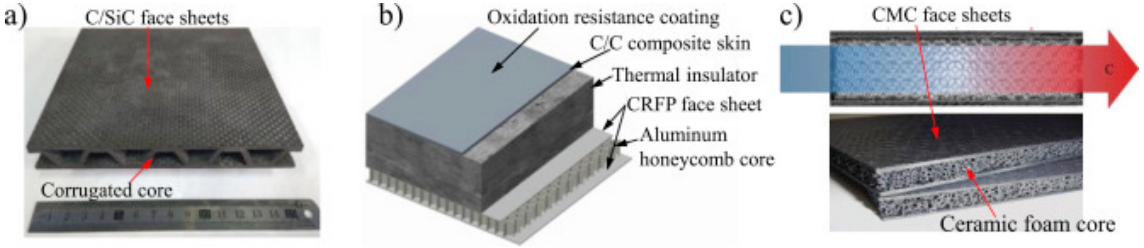


Liang et al (2021), JCOMA, 106481

Radar Absorbing Structure (RAS)

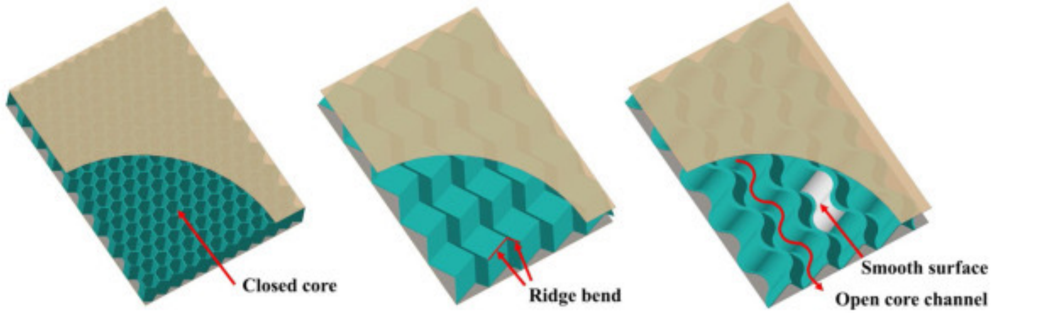
Thermal Protection System (TPS)

(foldcore is better ten honeycomb, corrugated, lattice/truss core)



Le, Ha, Goo (2021), JCOMB, 109301

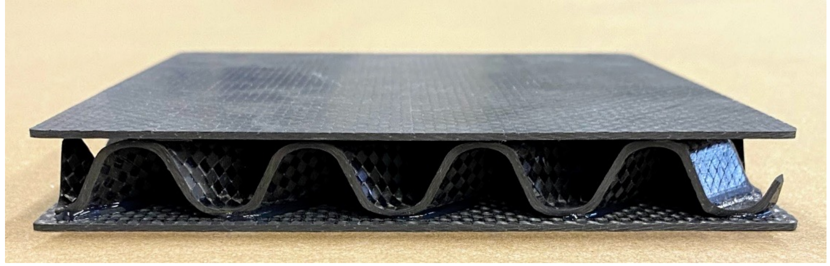
Thermal Management or Marine Structure



(a) Honeycomb structure (b) V-shaped foldcore structure (c) S-shaped foldcore structure

Deng et al. (2022), TWST, 109007

Questions?



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