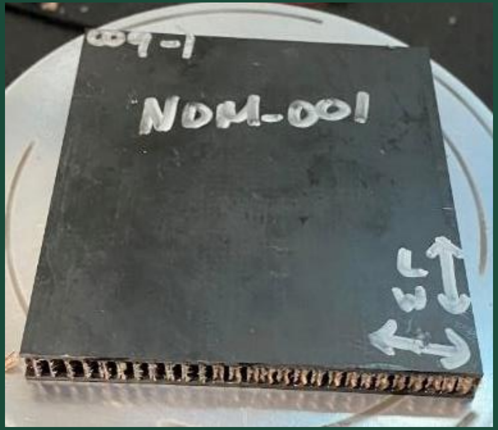
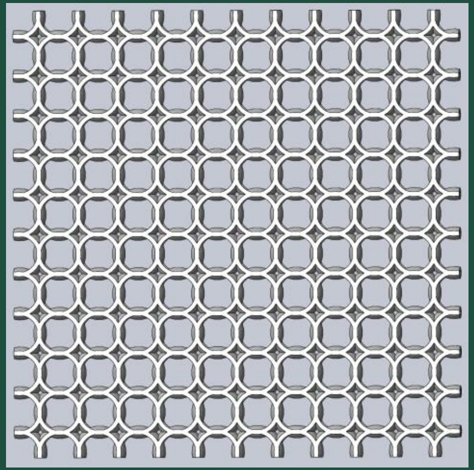
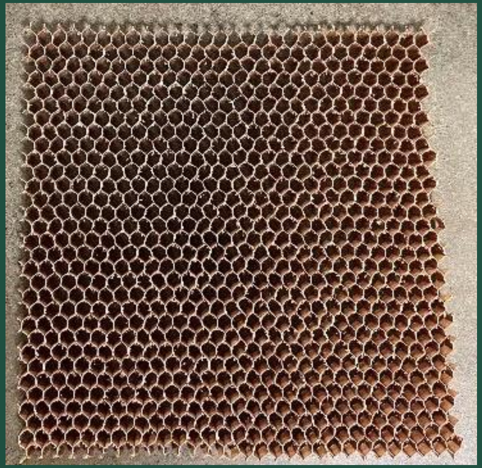
Advancing the Use of Sandwiched Composites through Hybrid Manufacturing the Core Structures

Savannah M. Rose, David A. Jack
Baylor University







Overview

Goal:

Create a novel core geometry, fabricate it using additive manufacturing (AM) and compare the mechanical properties to traditional aramid fiber honeycomb cores

Technical Approach:

Performed 3 ASTM tests (ASTM C364, ASTM C365, ASTM D7249) on both sandwich structures and compared the ultimate strength and strength to weight ratio

Outcomes: We found the hybrid structures perform better under flatwise compression and flexure compared to the traditional sandwich structures

Sandwich Structures Background

- Consists of 2 thin carbon fiber facesheets surrounding a core material of repeating structures
- Typical cores have been made of aramid fibers or aluminum
- Typically used as the rudder, flap, spoiler, and aileron of aircrafts [1]
- Can be used in the floor body of a car [2]
- Have good strength to weight ratio
- Manufacturing process limits the geometry

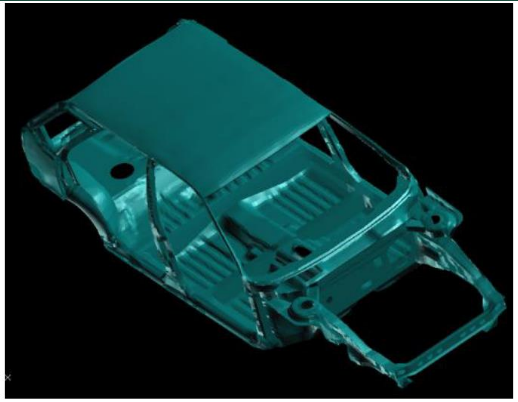
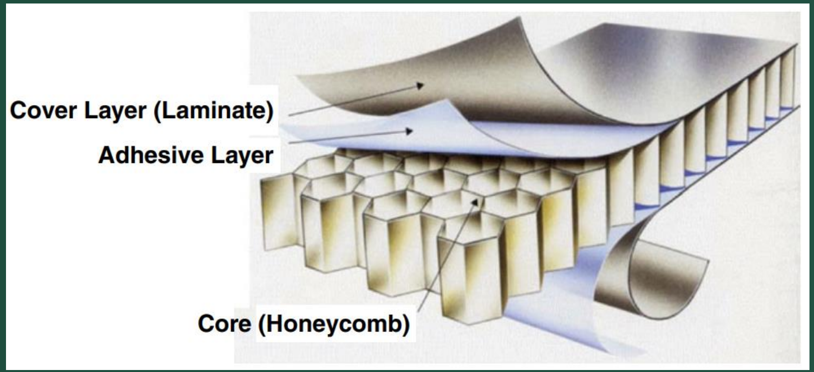
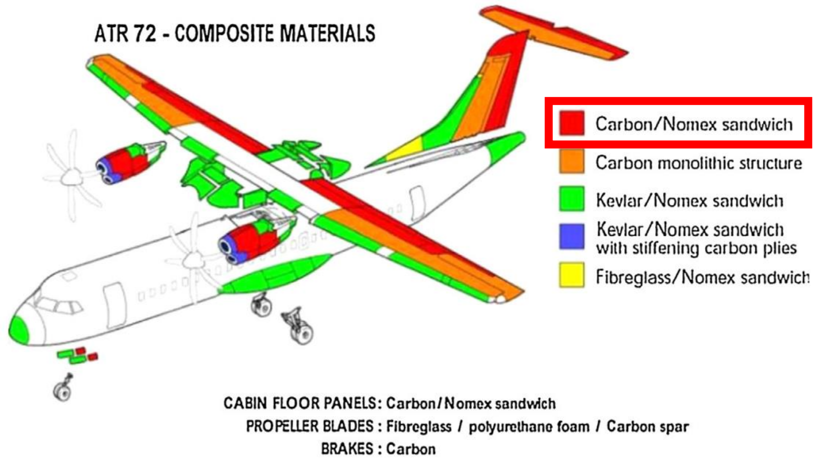


Fig. 1. FIAT car body-in-white CAD model.

[2] Hara and Ozgen, 2016, Transportation Research Procedia, Vol. 14



Friedrich and Almajid, 2013, Applied Composite Materials, Vol. 20

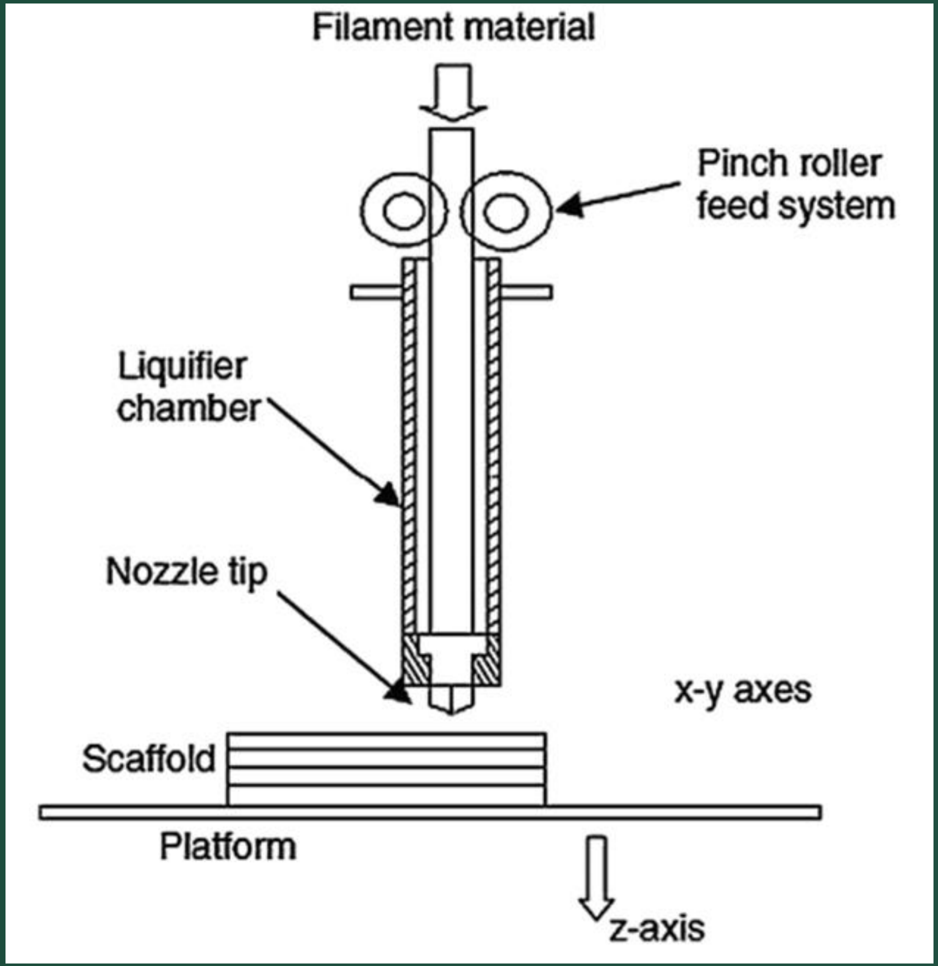


Castanie et al., 2020, Composites Part C: Open Access, Vol. 1

[1] V. M. Karbhari, Ed., “Ultrasonic Inspection of Sandwich Structures,” in *Non-destructive evaluation (NDE) of polymer matrix composites*, in Woodhead Publishing Series in Composites Science and Engineering, no. 43. New Delhi, 2013, pp. 415–421.

Additive Manufacturing

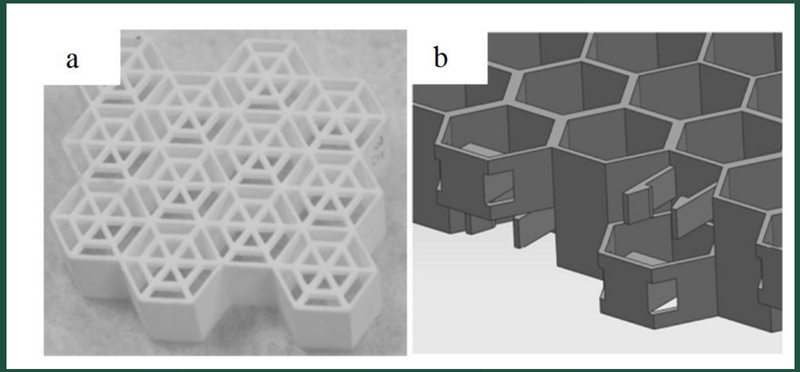
- A method of manufacturing where components are fabricated layer by layer
- Less waste than traditional manufacturing processes
- More geometric freedom than other manufacturing processes
- Fused filament fabrication was used in this study



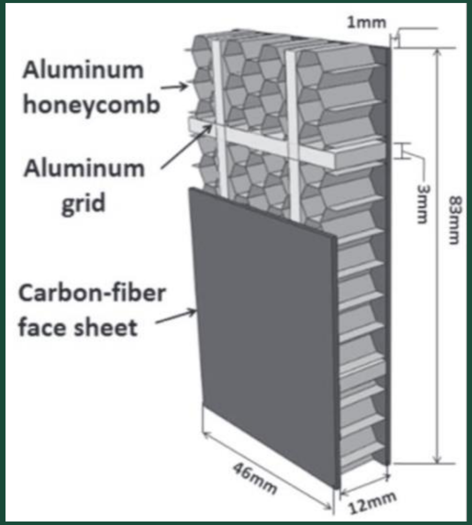
Roshchupkin et al., 2021, Materials Today: Proceedings, Vol. 38

Geometrical Freedom is Advantageous

- Snap in connections
- Multiple core types of aramid fibers
- Reinforced aluminum honeycomb core
- Reinforced aramid fiber cores
- Current methods to achieve such freedom involve several steps

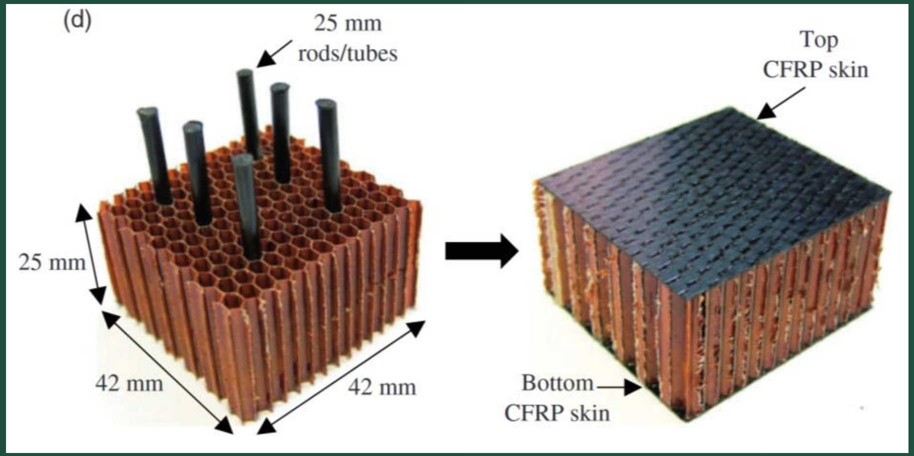


Riss et al., 2014, Physics Procedia, Vol. 56



Sun et al., 2016, Composites: Part B, Vol. 94

Hou et al., 2014, Composites: Part B, Vol. 59

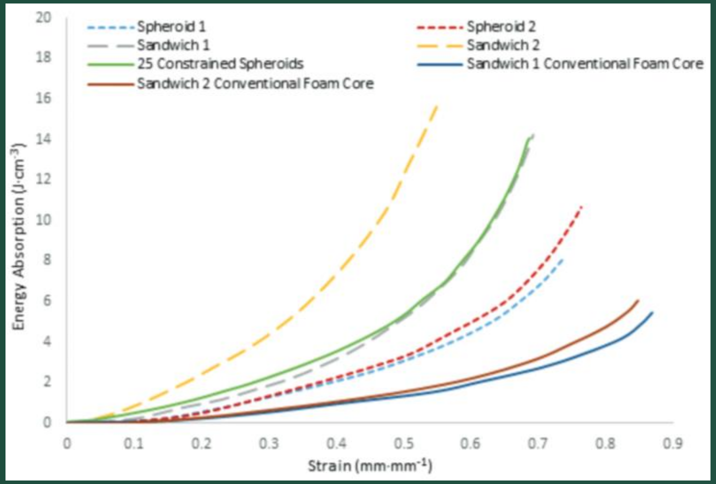


Alia et al., 2018, Journal of Reinforced Plastics and Composites, Vol. 37

Previous Work

- A foam spheroid core was created and compared to traditional aluminum foam cores
- The spheroidal foam core was compared to aluminum foam cores through quasi-static and dynamic compression tests
- The spheroidal core outperformed the traditional foam core

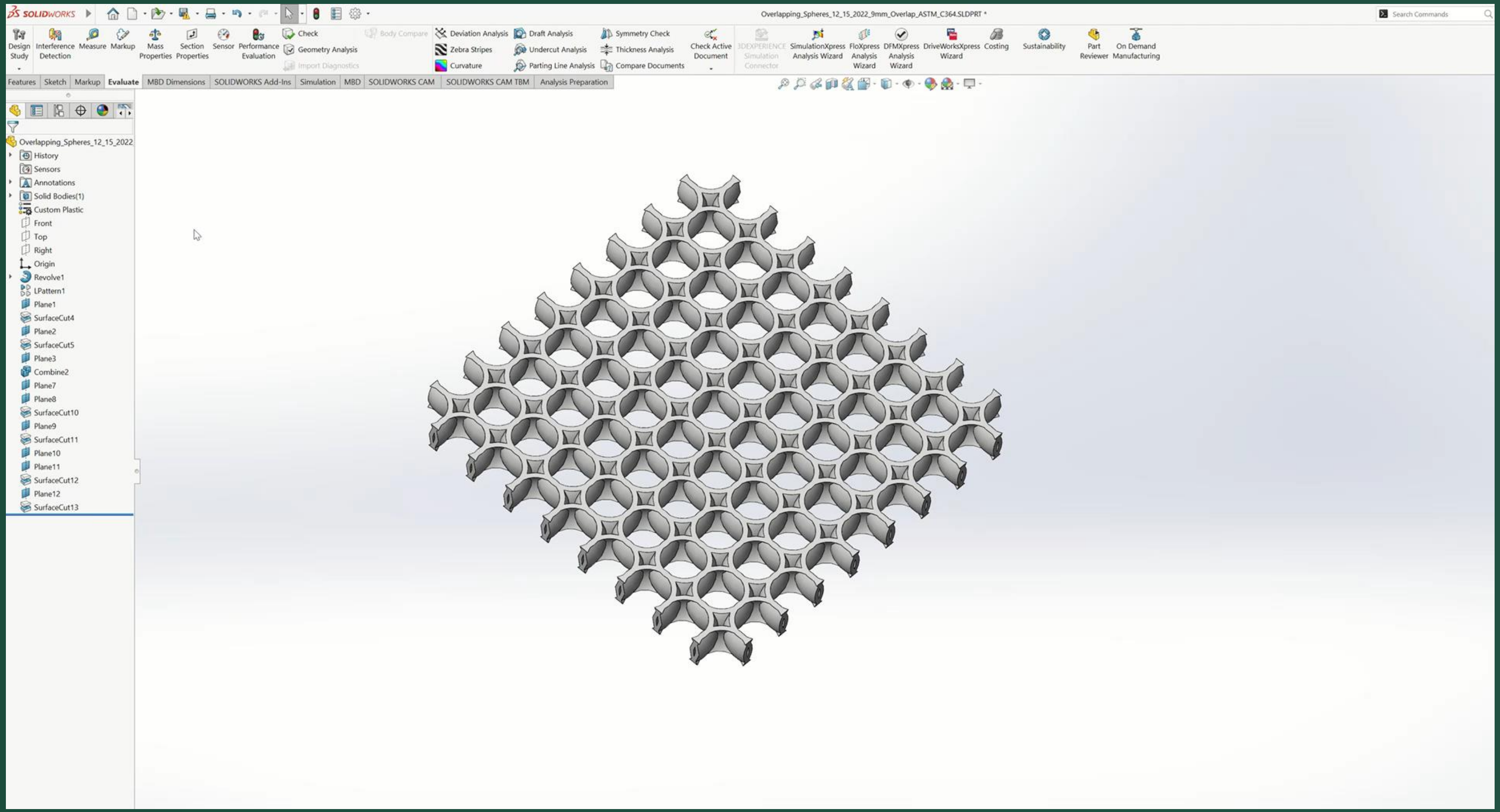
Ruiz-Roman et al., 2020, Revista de Metalurgia,Vol. 56



Ruiz-Roman et al., 2020, Revista de Metalurgia,Vol. 56

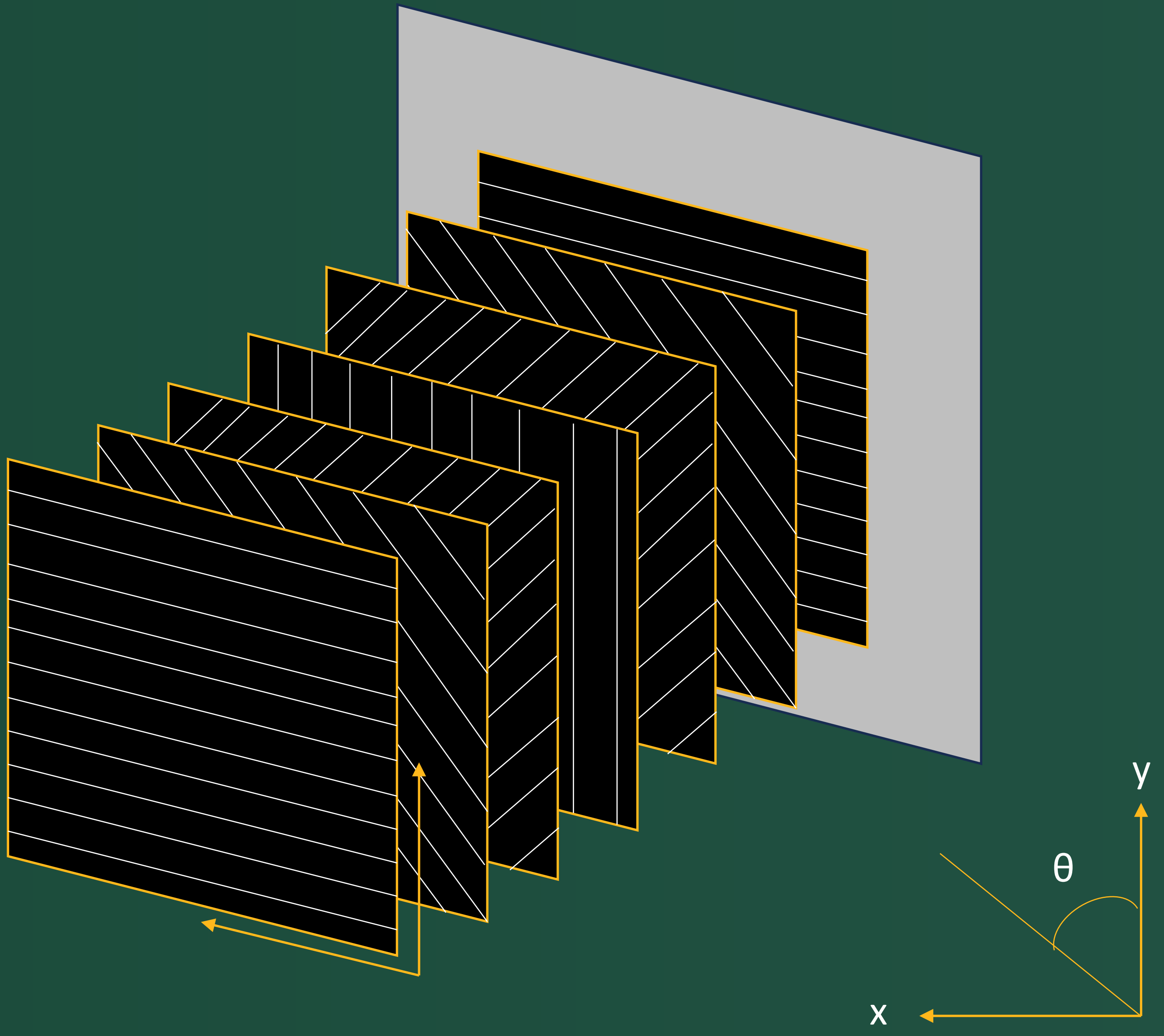
Core Design Process

- 9 mm center to center distance
- 0.8 mm wall thickness
- 12 mm sphere diameter
- Spheres distribute stress more evenly than other geometries



Facesheet Manufacturing Method

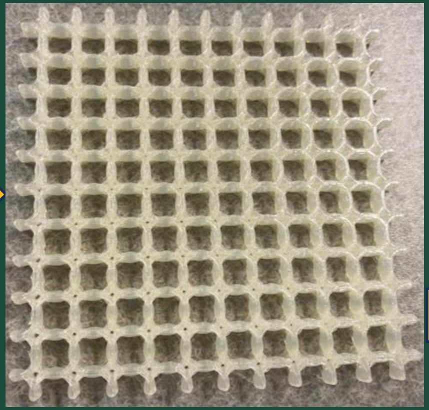
- Laminates made from 7 layers unidirectional prepreg
  - 0.006” thick (Rockwest Composites)
  - Each laminate was 1mm thick
- Layup: [0/±45/90/∓45/0]
- Fabricated on an aluminum tool with release spray (Loctite Frekote)
- Each layer was pressed before adding the next layer
- Final facesheets were cut from the cure laminate using a Wazer waterjet cutter



Manufacturing Method

Essentium HSE 180

Printed Core



Loctite Adhesive
9309A

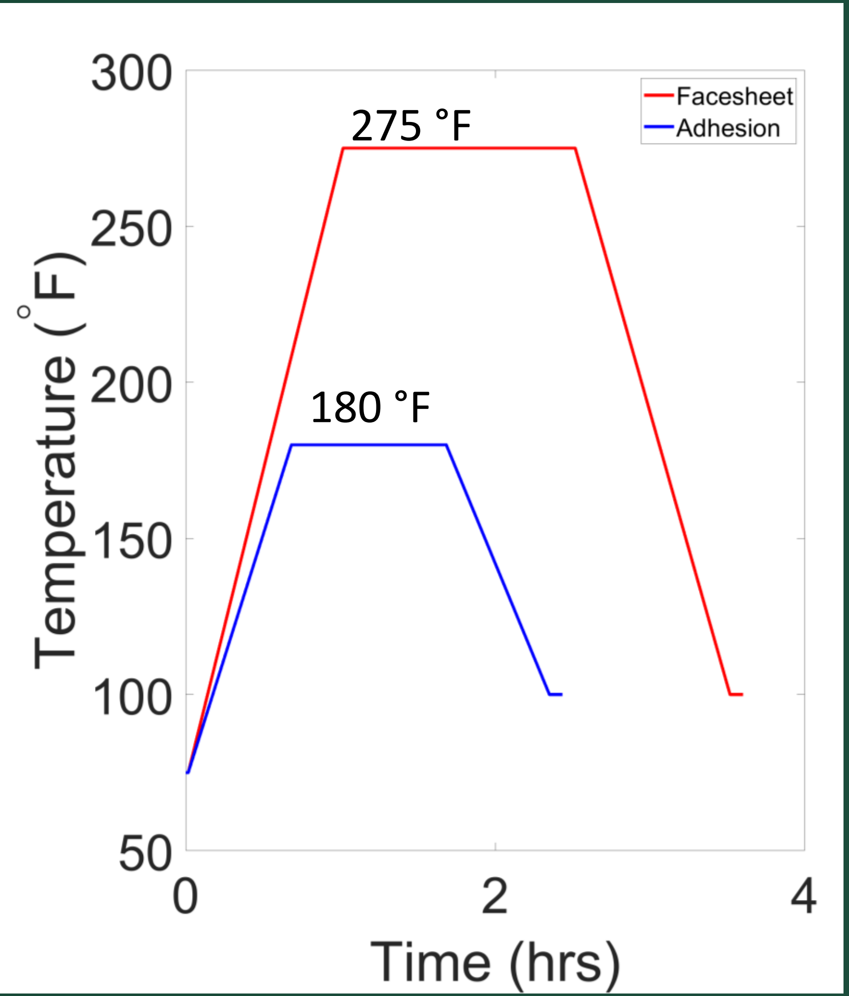
Carver Hot Press

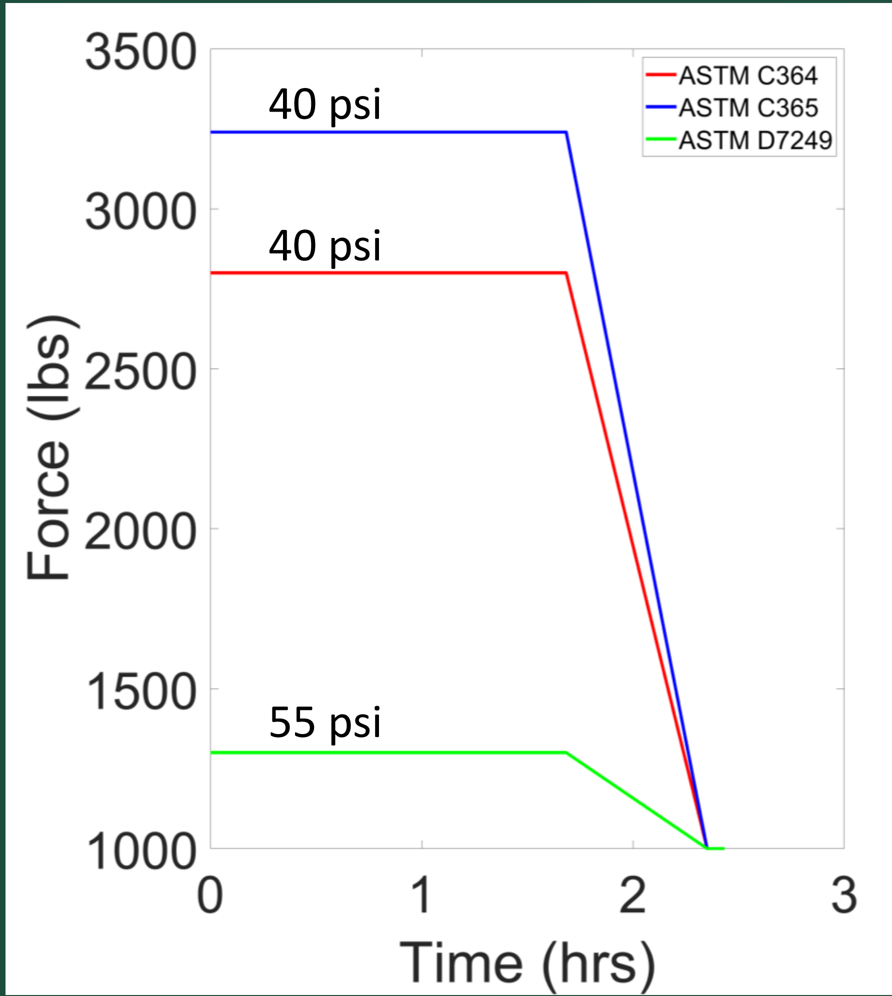
Carver Hot
Press

Carbon Fiber
Unidirectional Prepreg

Wazer Water
Jet Cutter

Manufacturing Method – Cure Schedules





Test Matrix

- 3 tests were performed: edgewise compression (ASTM C364), flatwise compression (ASTM C365), and flexure (ASTM D7249)
  - Carbon fiber laminates perform worse in compression
  - Buckling is a common failure mode for honeycomb cores
- 3 samples were manufactured and tested for each test type

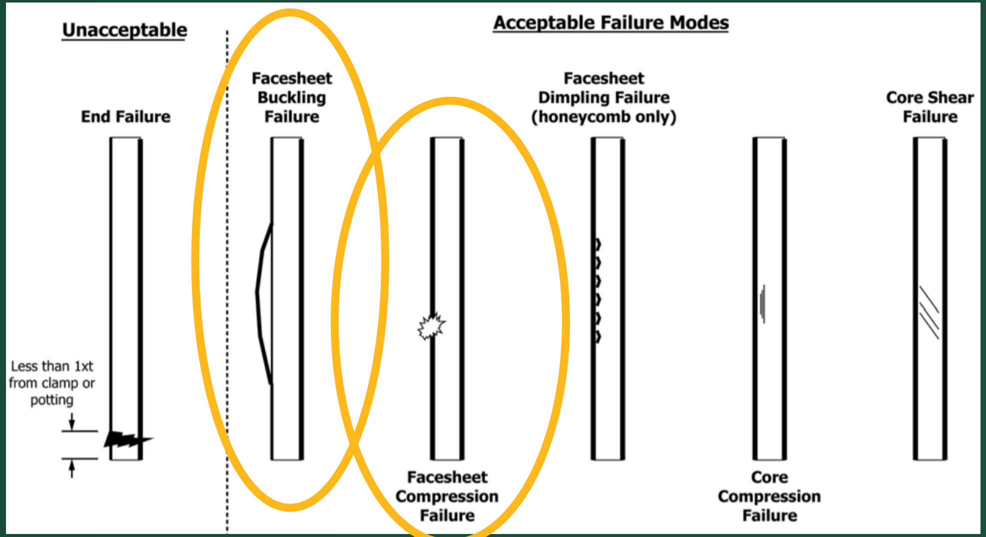
$$\sigma_{11} = \frac{P_{max}}{A} \quad (1)$$

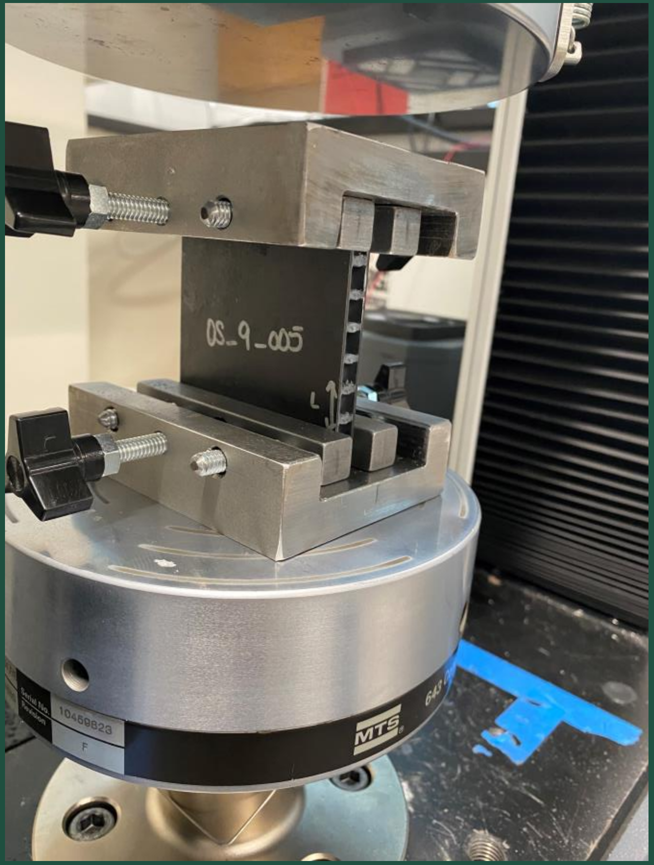
$$E_c = \frac{(\Delta P)t}{(\Delta h)A} \quad (2)$$

$$\sigma_{flex} = \frac{M_{max}y}{I} \quad (3)$$

Test Matrix: ASTM C364

- Laminates were 3”x3”
- Cores were ¼” thick
- Edges were leveled with a surface grinder
- There are several failure modes acceptable by the standard
- The fixture was carefully leveled on both sides of the sample





ASTM C364

Test Matrix: ASTM C365

- Laminates were 3”x3”
- Cores were ¼” thick
- The samples were centered on the compression platen
- The compression platen self levels to evenly load the sample with the springs on the top half

ASTM C365

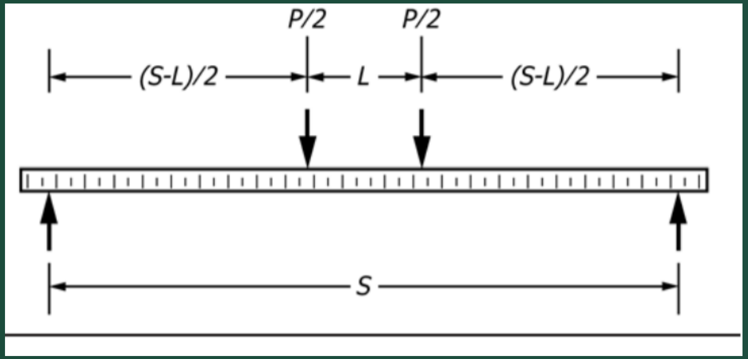
Test Matrix: ASTM D7249

- Samples were 19.5”x1.42”
  - Size was smaller than the standard due to manufacturing capabilities
- Test span was 18.5”
- The tests were third-span
  - Load span was 6.16”
- Could not surface grind due to the size

ASTM D7249

Configuration		Support Span (*S*)	Load Span (*L*)
Standard	4-Point	560 mm [22.0 in.]	100 mm [4.0 in.]
Non-Standard	3-Point (Mid-span)	*S*	0.0
	4-Point (Quarter-Span)	*S*	*S*/2
	4-Point (Third-Span)	*S*	*S*/3

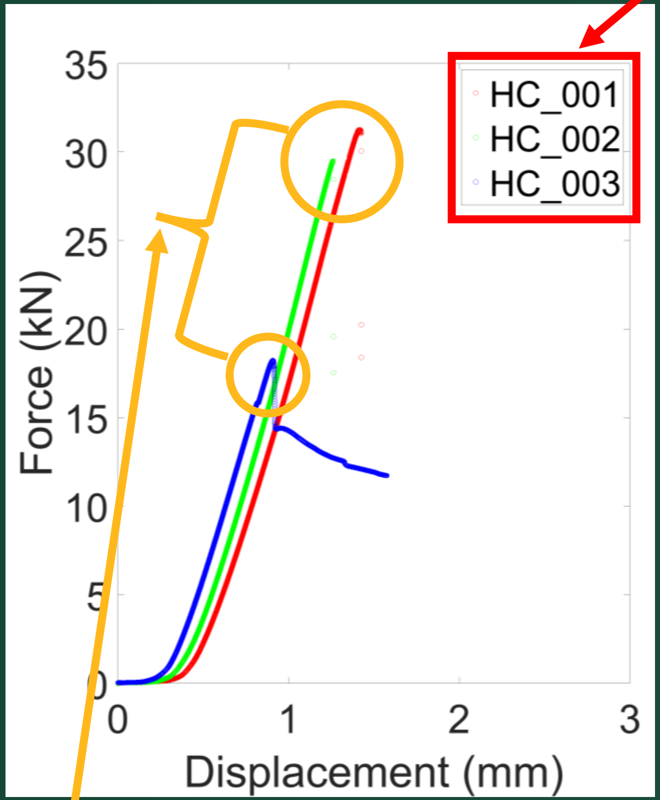
FIG. 2 Loading Configurations

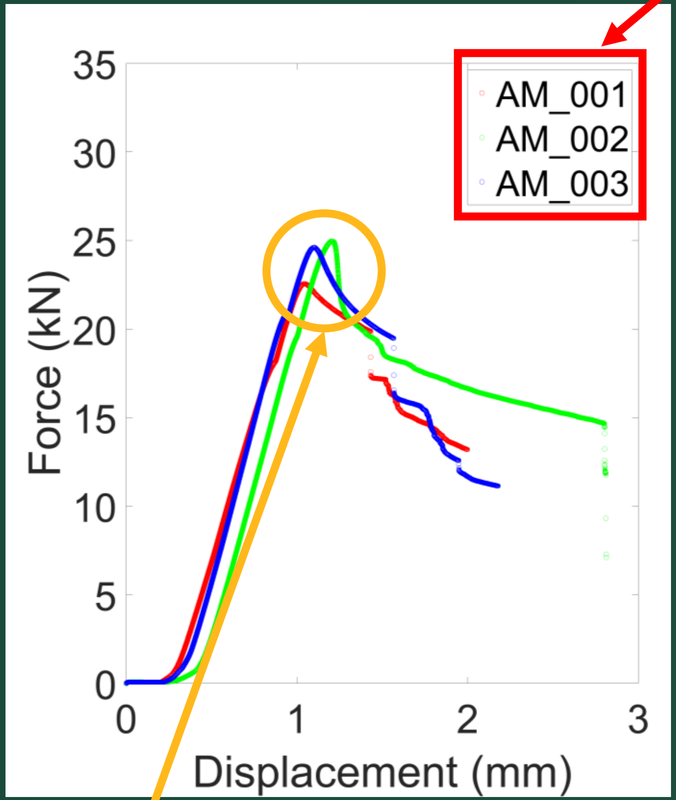


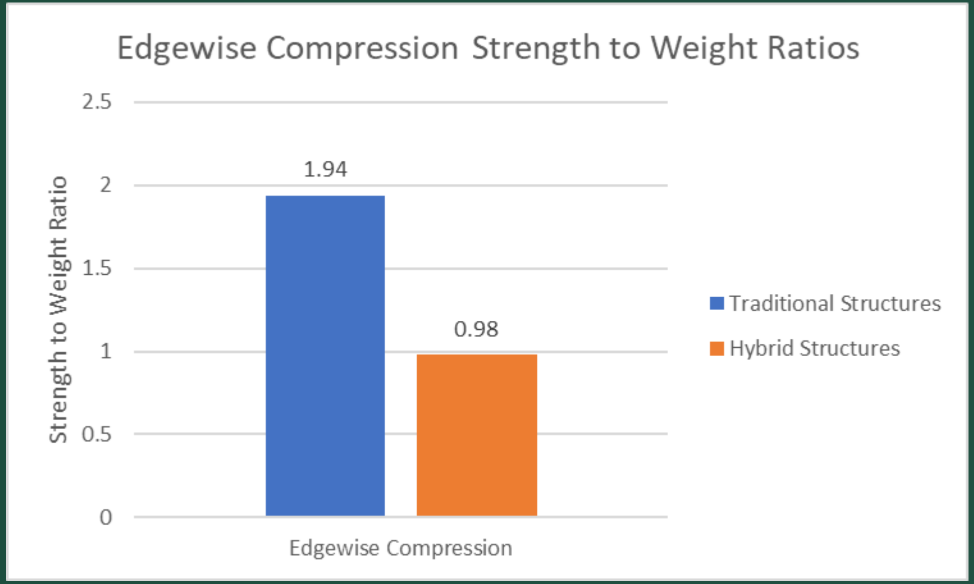
Edgewise Compression Results (ASTM C364)

Aramid Fiber Structures

Nylon AM Structures







$\sigma_{11,avg}$ = 42.7 MPa
Std Dev = 11.68 MPa
$E_{11,avg}$ = 5.52 GPa

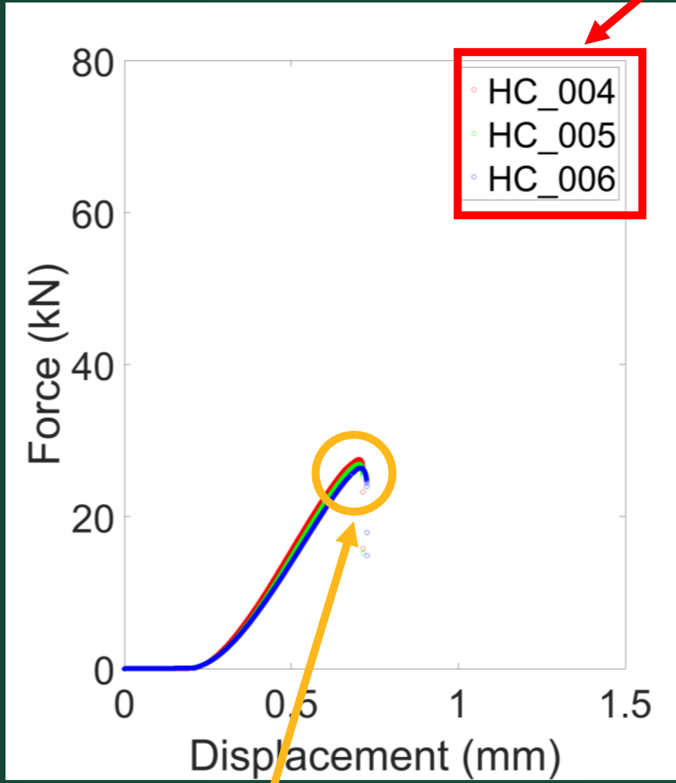
$\sigma_{11,avg}$ = 33.7 MPa
Std Dev = 6.00 MPa
$E_{11,avg}$ = 4.92 GPa

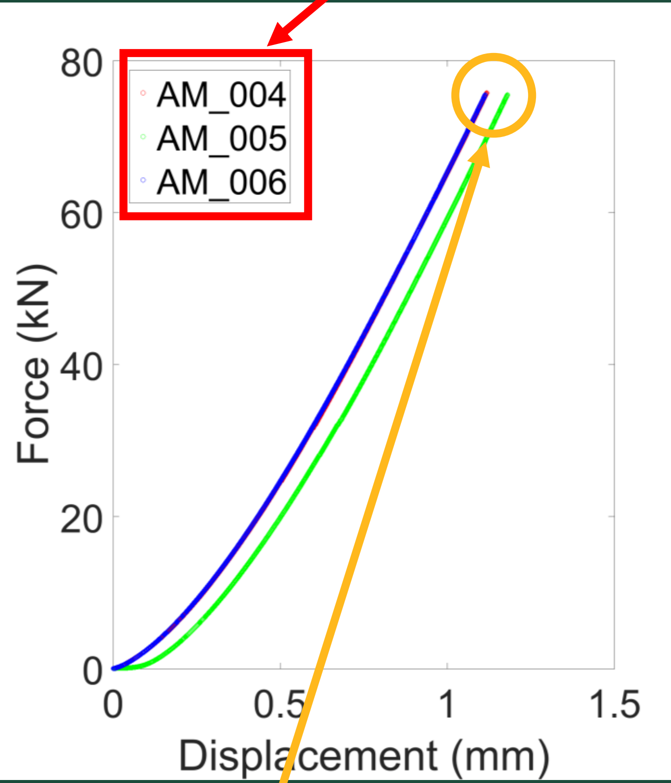
AM Mass: 34.5 g
HC Mass: 21.9 g

Flatwise Compression Results (ASTM C365)

Aramid Fiber Structures

Nylon AM Structures





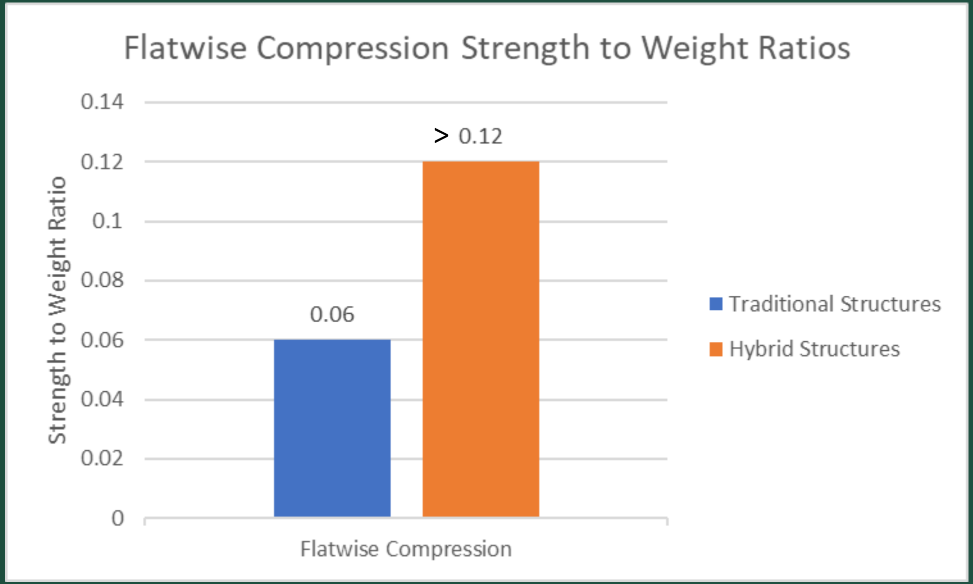
$\sigma_{33,avg}$ = 2.7 MPa

Std Dev = 0.064 MPa

$E_{33,avg}$ = 59.3 MPa

$\sigma_{33,avg}$ = >7.3 MPa

$E_{33,avg}$ = 63.5 MPa



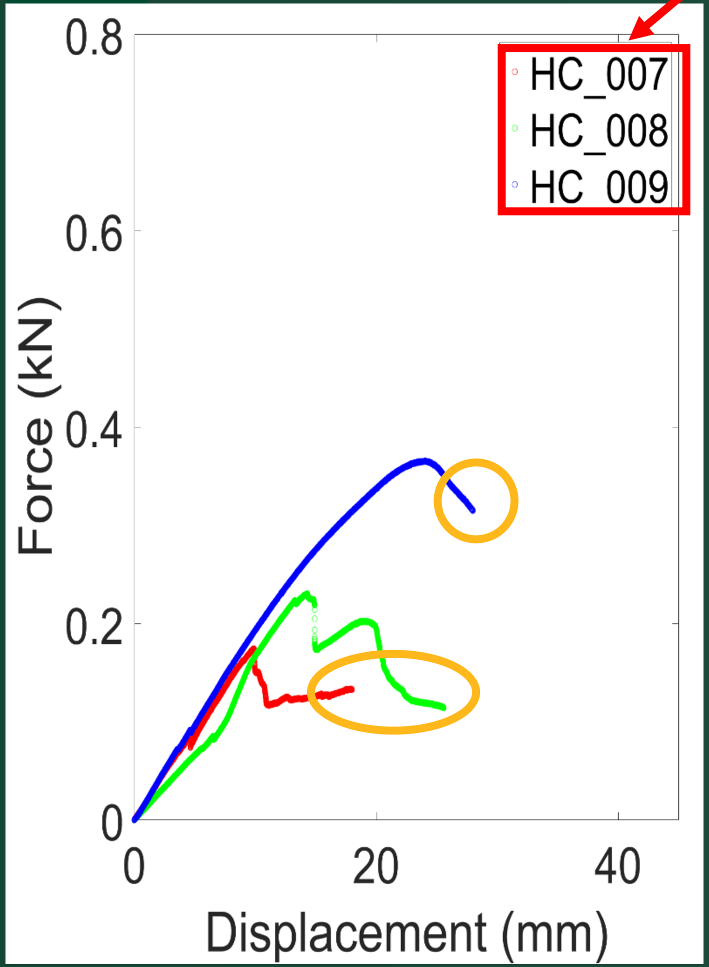
AM Mass: 59.0 g

HC Mass: 40.2 g

Flexure Testing (ASTM D7249)

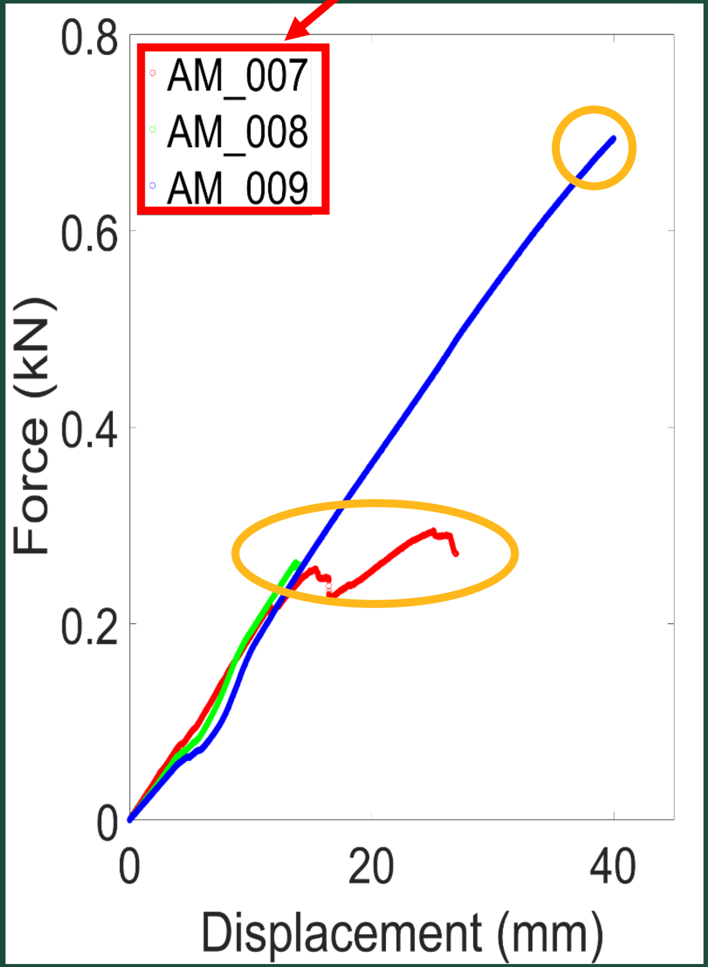
Aramid Fiber Structures

Nylon AM Structures



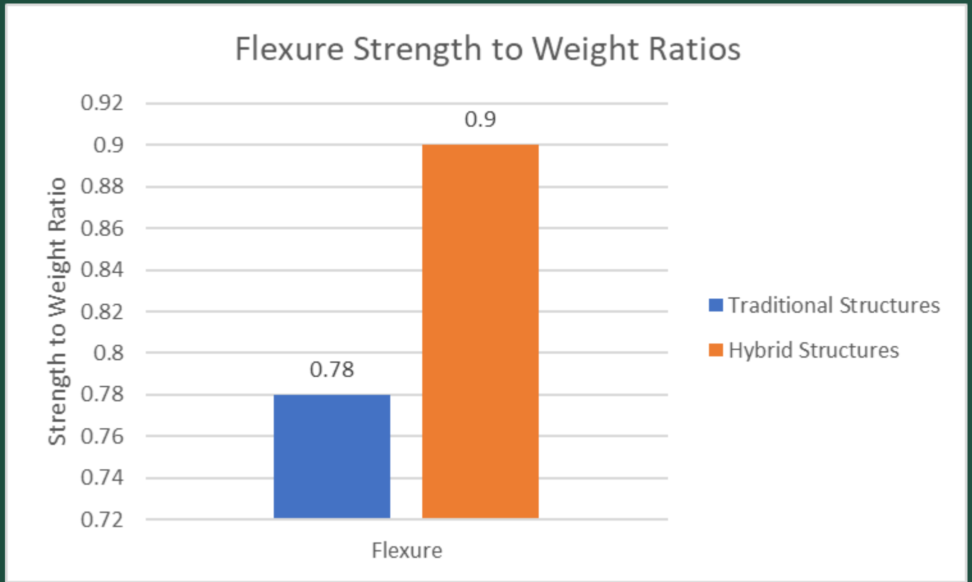
$\sigma_{flex,avg}$ = 48.9 MPa

Std Dev = 18.2 MPa



$\sigma_{flex,avg}$ = 84.2 MPa

Std Dev = 39.9 MPa

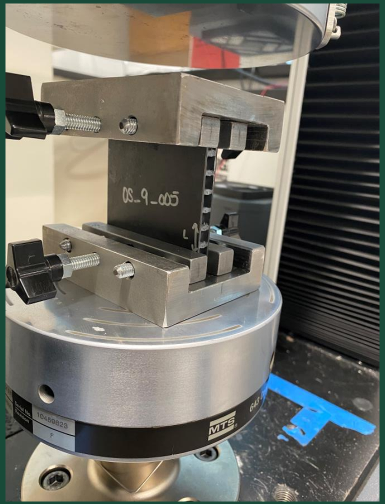


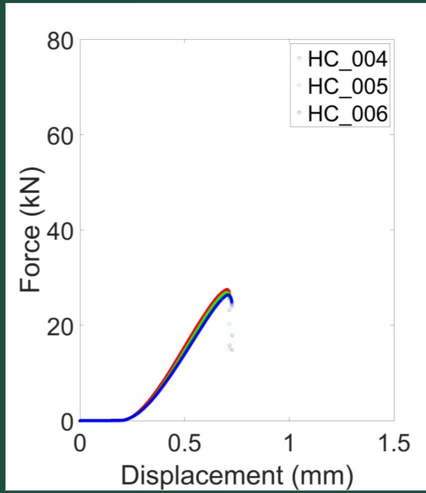
AM Mass: 93.1 g

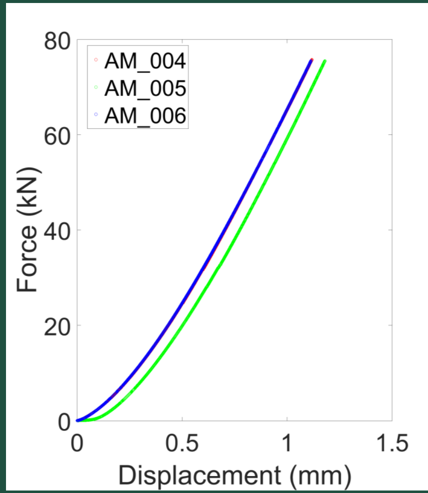
HC Mass: 62.2 g

Conclusions and Future Work

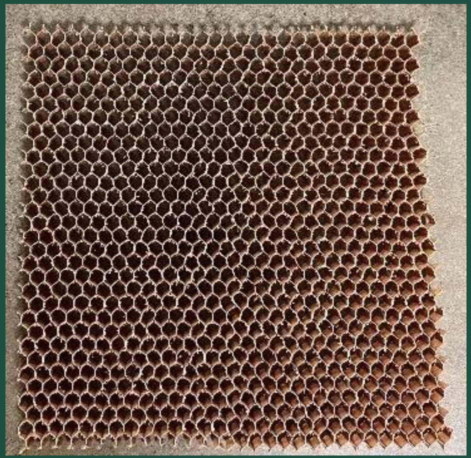
- Mechanical tests were used to compare the performance of the AM core in a hybrid sandwich structure to traditional sandwich structures
- The hybrid structures performed comparably in edgewise compression (ASTM C364), and significantly better in flatwise compression (ASTM C365) and flexure (ASTM D7249)
    - Both in ultimate load capabilities and in strength to weight ratio
- Other patterns of spheres can be used to determine an optimum structure pattern for the specific application

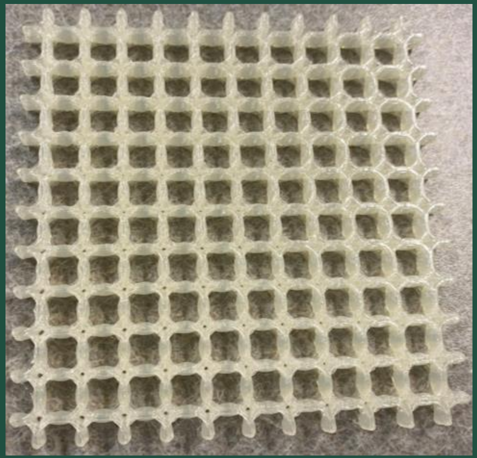


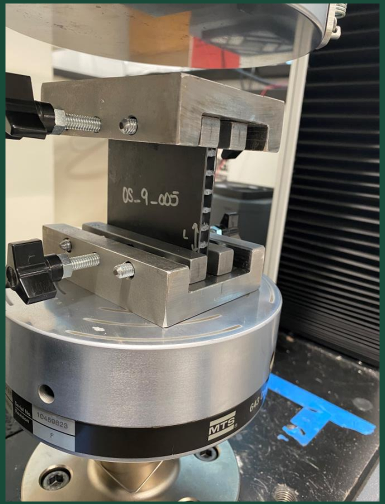


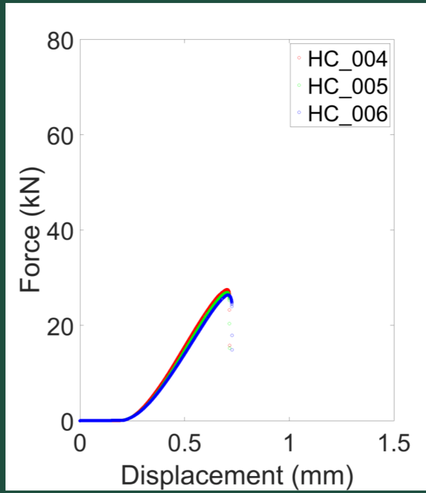


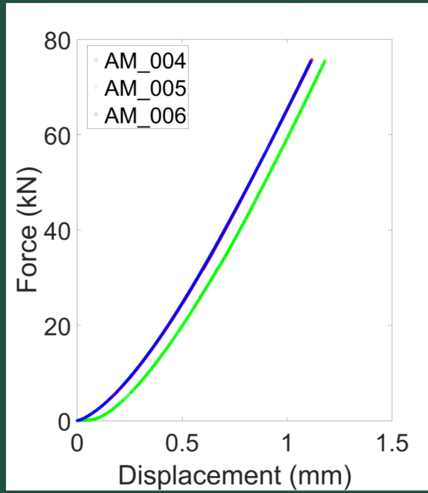
Thank you to L3Harris for funding this work








80
60
40
20
0
Force (kN)
0
0.5
1
1.5
Displacement (mm)
HC_004
HC_005
HC_006


80
60
40
20
0
Force (kN)
0
0.5
1
1.5
Displacement (mm)
AM_004
AM_005
AM_006

Questions?