PURDUE UNIVERSITY

Composites Manufacturing & Simulation Center

EPIC/ToF – Stave Prototyping Efforts

January 2024 ePIC Collaboration Meeting

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10 January 2024

Manufacturing Deformation Simulation

- Need – the first stave prototype manufactured at Purdue in Summer 2023 warped upon curing.
- This warpage comes from internal residual stresses from anisotropic coefficient of thermal expansion mismatch between different materials/structures used in the stave.
- We cannot completely remove this internal stress, but we can minimize it by controlling the cure cycle of the composite.

- In this talk –

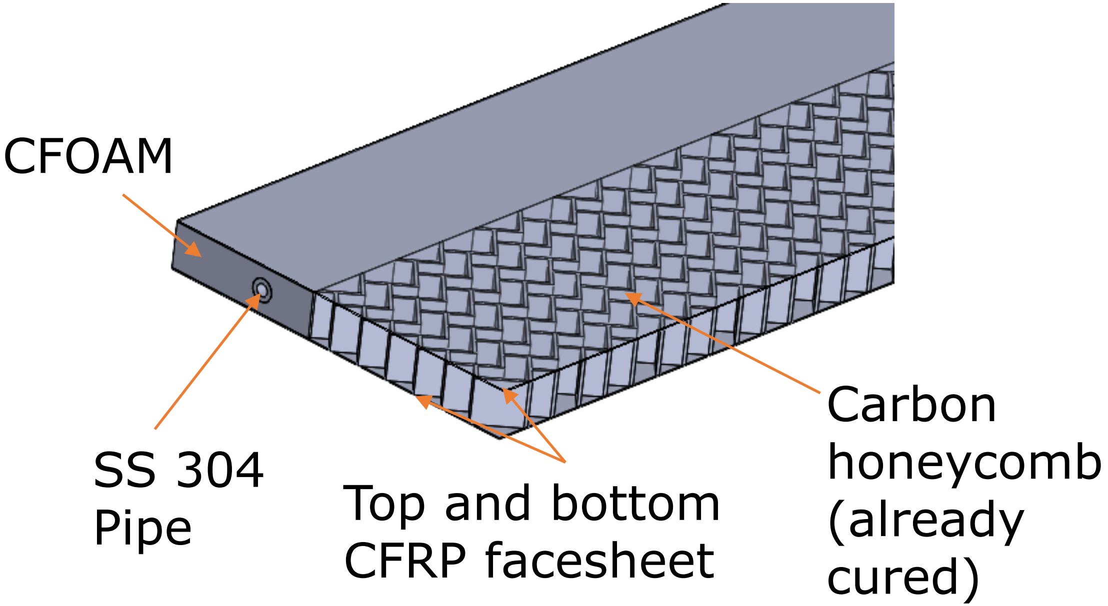
1. Manufacturing simulation results
2. Report on raw material procurement – all delivered and available at Purdue CMSC.
3. Manufacturing plan
4. Upcoming task list

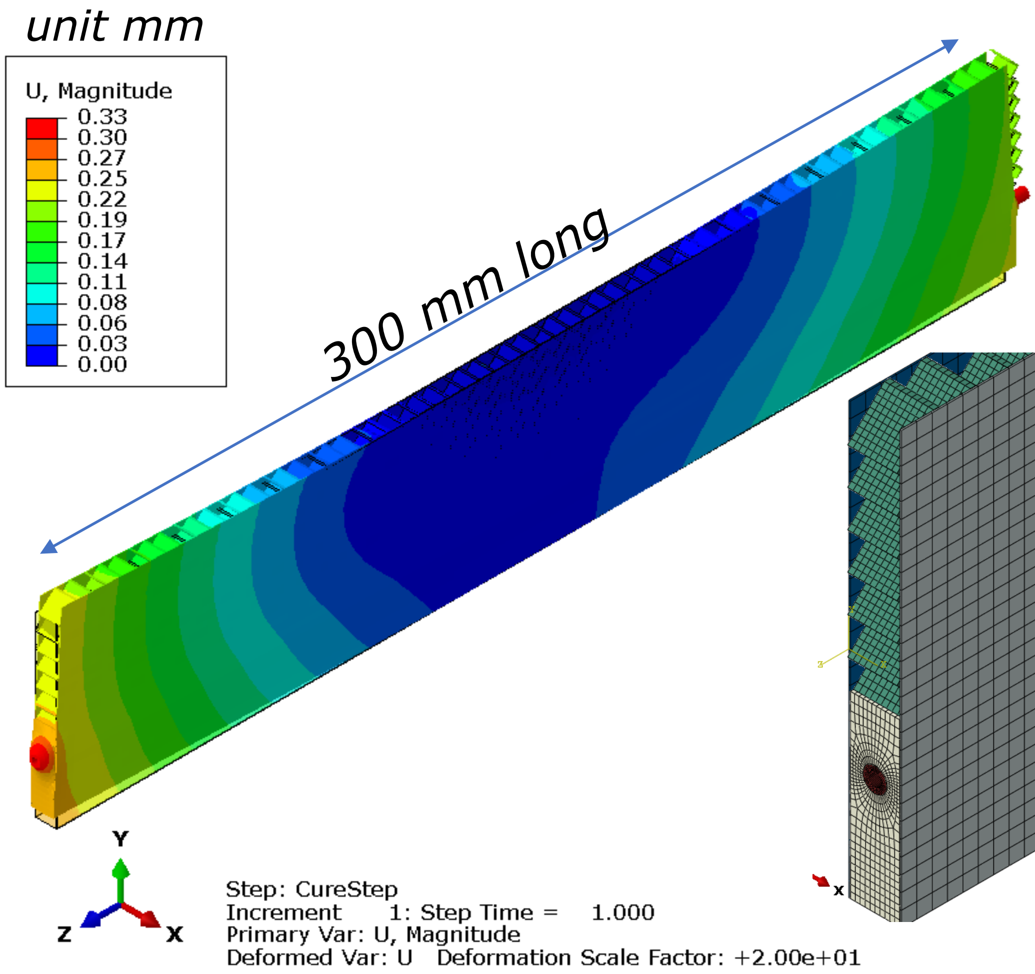
Nomenclature –
miniSTAVE : 300 mm long
halfSTAVE : 1.35 m long (half length)
fullSTAVE : full length

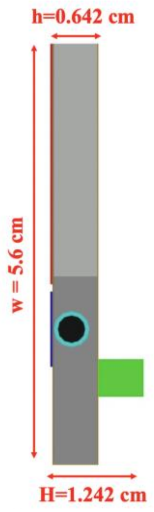
Cross-section always is the actual designed cross-section

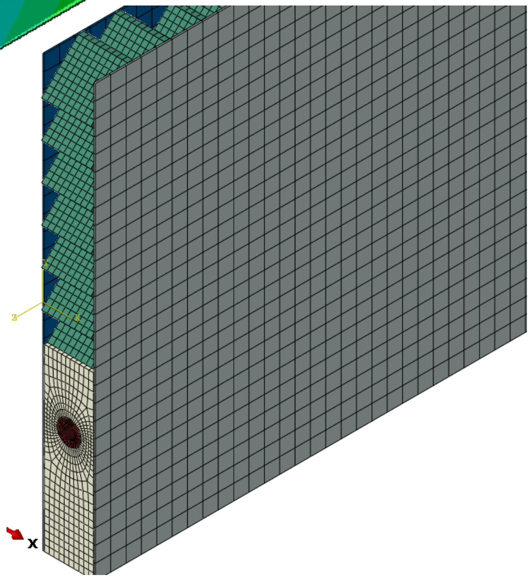
Motivation of problem in curing everything together at manufacturer recommended cure cycle

- Unsymmetric core with vastly different (anisotropic) CTEs/effective CTE
- Thus, results in warpage at recommended curing temperature of 180°C(350°F)
- Up to 300-micron deflection on each side (600 micron effective) on a 300 mm long miniSTAVE prototype – *up to 3.6//7.2// mm for a 2.6 m fullSTAVE*





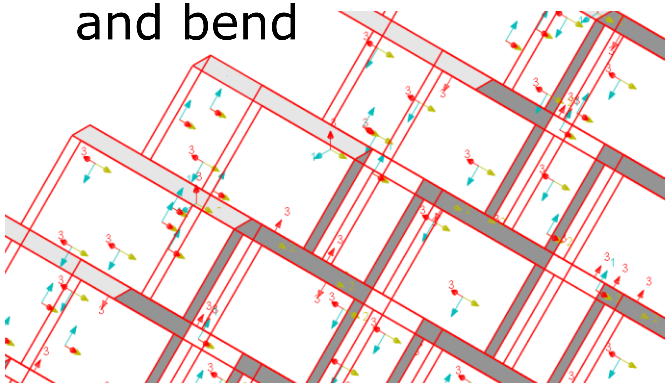


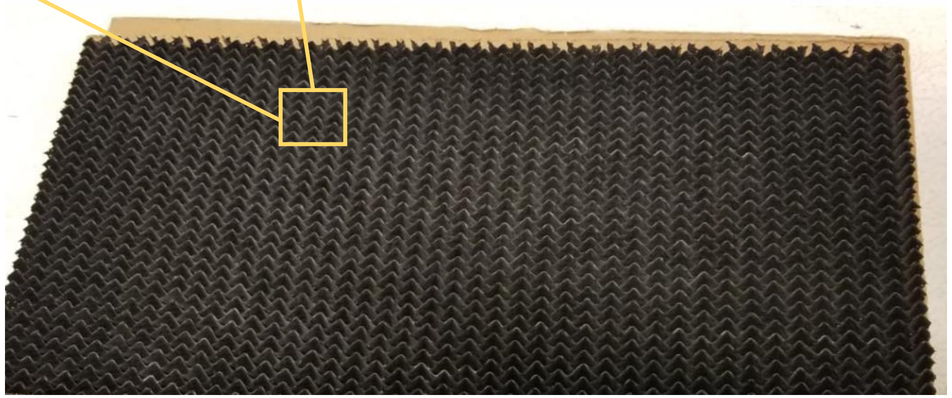


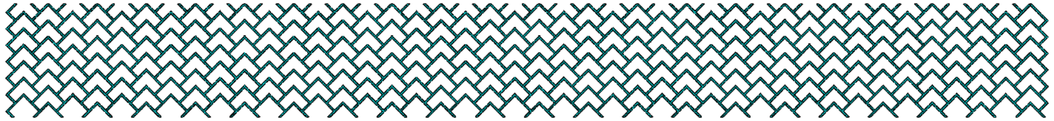
Carbon Honeycomb Modelling

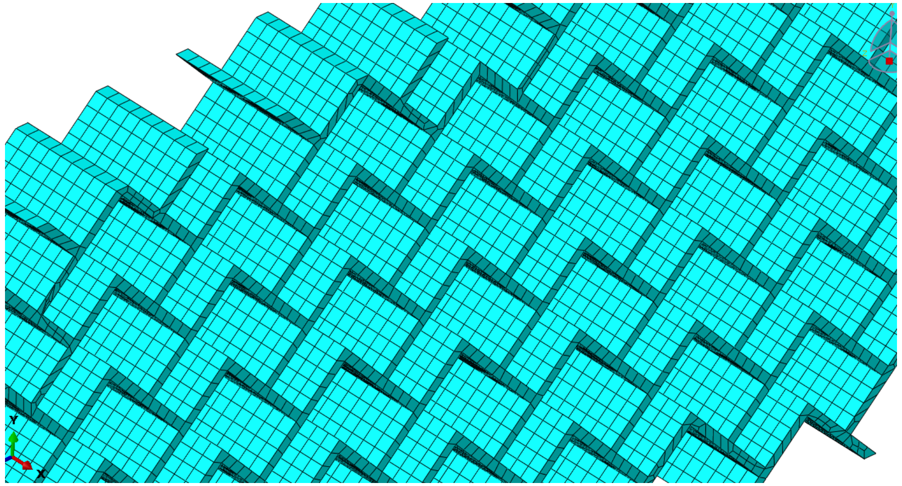
- APEX Carbon Flex Core – PMT material data.
- Cannot use regular "homogenized" properties since the shape of the honeycomb is not "honeycomb"/hexagonal – need to write out the homogenization math using Mechanics of Structure Genome code - upcoming
- Currently modelled explicitly
- Adhesive modelling between two laminates NOT implemented. Modelled as continuous.

Orientation set along each face and bend



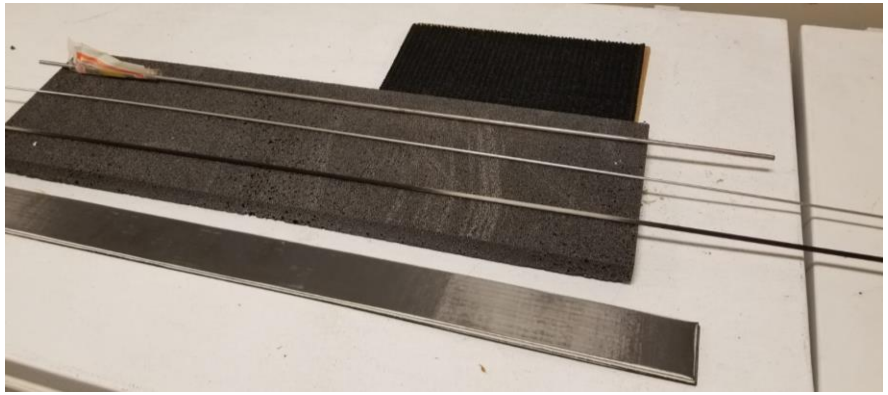






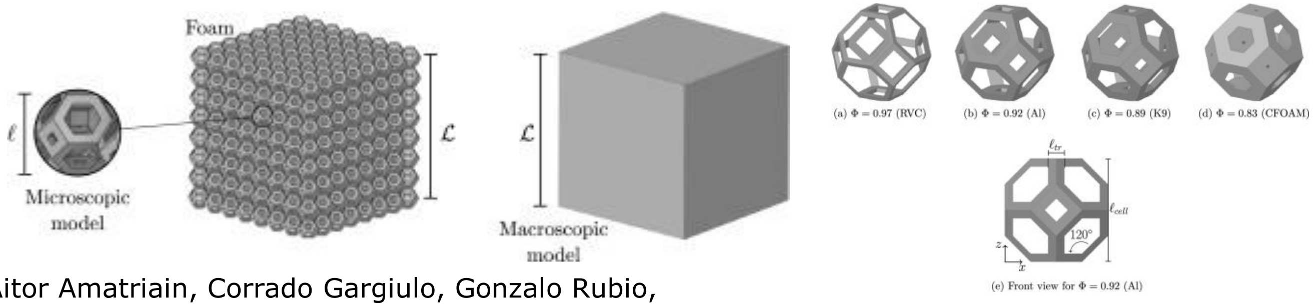
CFOAM HTC35 carbon foam alternative to K9

- CFOAM modelled as isotropic homogeneous solid.
- This is okay for now
- There is huge non-homogeneity in the actual product → need to study the effect of these on thermal performance and see if it is acceptable



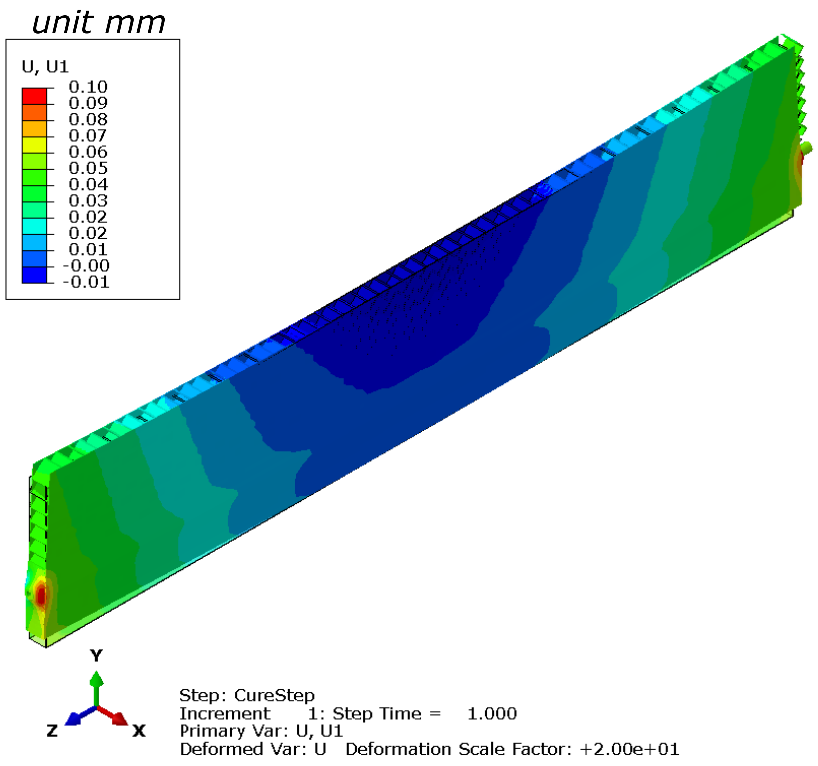
CFOAM® 35 HTC TYPICAL PROPERTIES (METRIC)

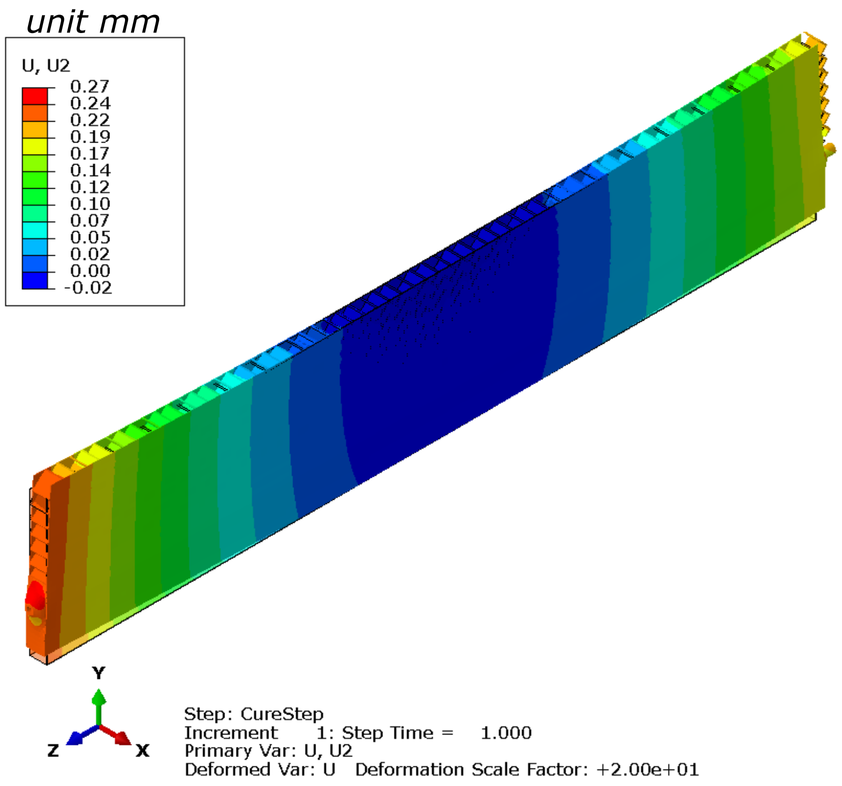
	Test	Units	CFOAM35 HTC
Nominal Density	ISO 12985-2	cc	0.40-0.50
Compressive Strength	ISO 18515	MPa	1.50-1.80
Compressive Modulus	ISO 18512	MPa	100-400
Tensile Strength	ISO 12986-2	MPa	0.9-1.0
Shear Strength	ISO 12986-2	MPa	1.0-4.0
Coefficient of Thermal Expansion	ISO 14420	ppm/°C	1.9-2.1
Thermal Conductivity	ISO 12987	W/m-K	140-180
Maximum Operational Use Temperature	*Environment Dependent*	°C	400
Electrical Resistance	ISO 11713	milliohm-cm	3-4
Pore Volume	Microscopy	%	> 70%
Mean Pore Size	Microscopy	Microns	1200

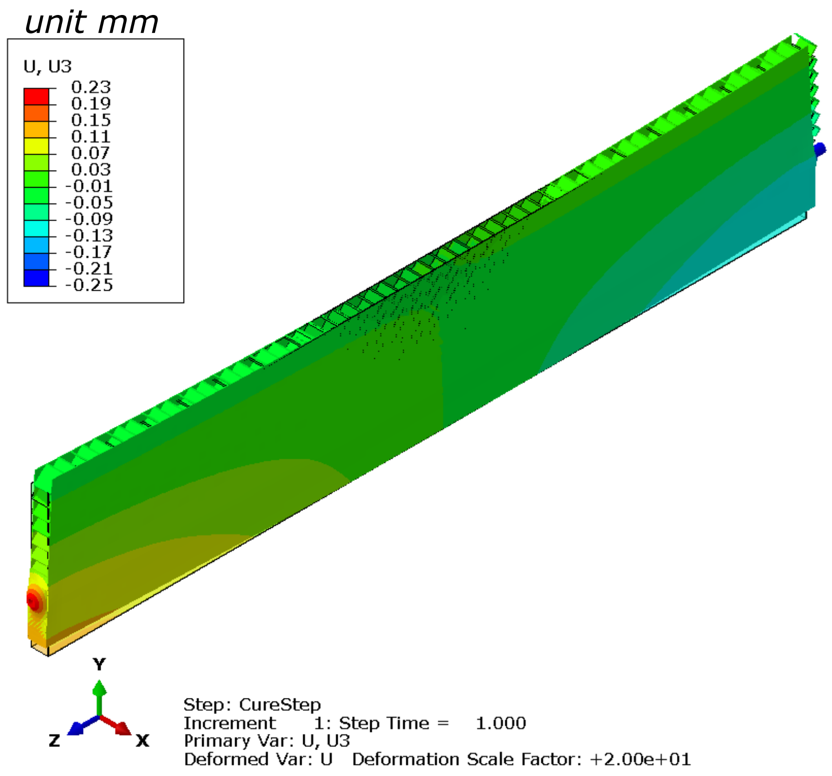


Aitor Amatriain, Corrado Gargiulo, Gonzalo Rubio,
Numerical and experimental study of open-cell foams for the characterization of heat exchangers,
International Journal of Heat and Mass Transfer, Volume 217,2023,124701,ISSN 0017-9310,
https://doi.org/10.1016/j.ijheatmasstransfer.2023.124701.

Deformation components

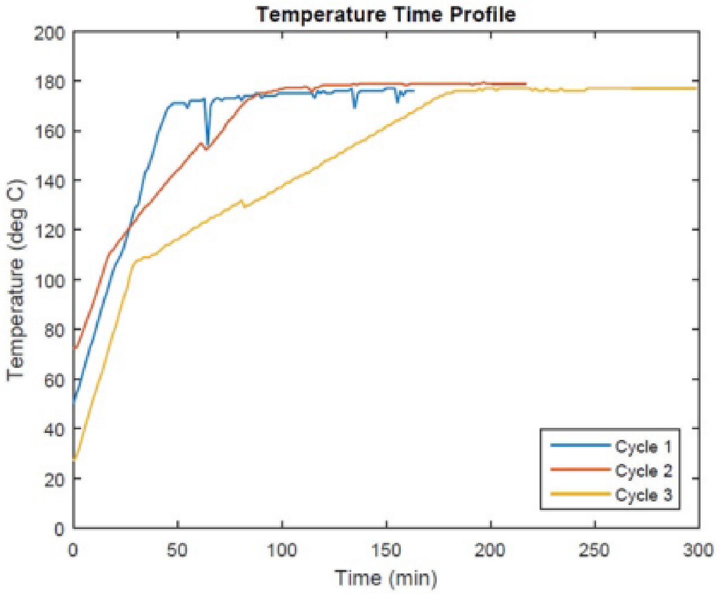




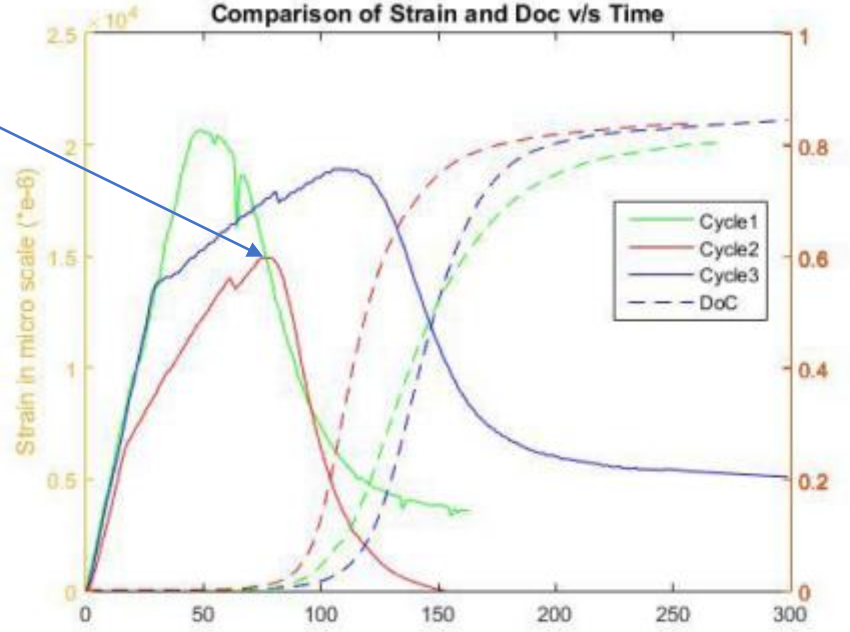


What can we do about it ?

- Changing cure cycle such that we get the lowest peak strain in the part
- We achieve the same degree of cure and thus the needed stiffness. Flow behavior of the resin changes (thus wetting/co-curing of the foam and honeycomb core to facesheet)
- This might affect thermal performance (?) – will be studied with analytical models and experimentation
- ***Manufacturing 2 miniSTAVE prototypes with two different cure cycles to see which one will give minimum warpage/deformation.***



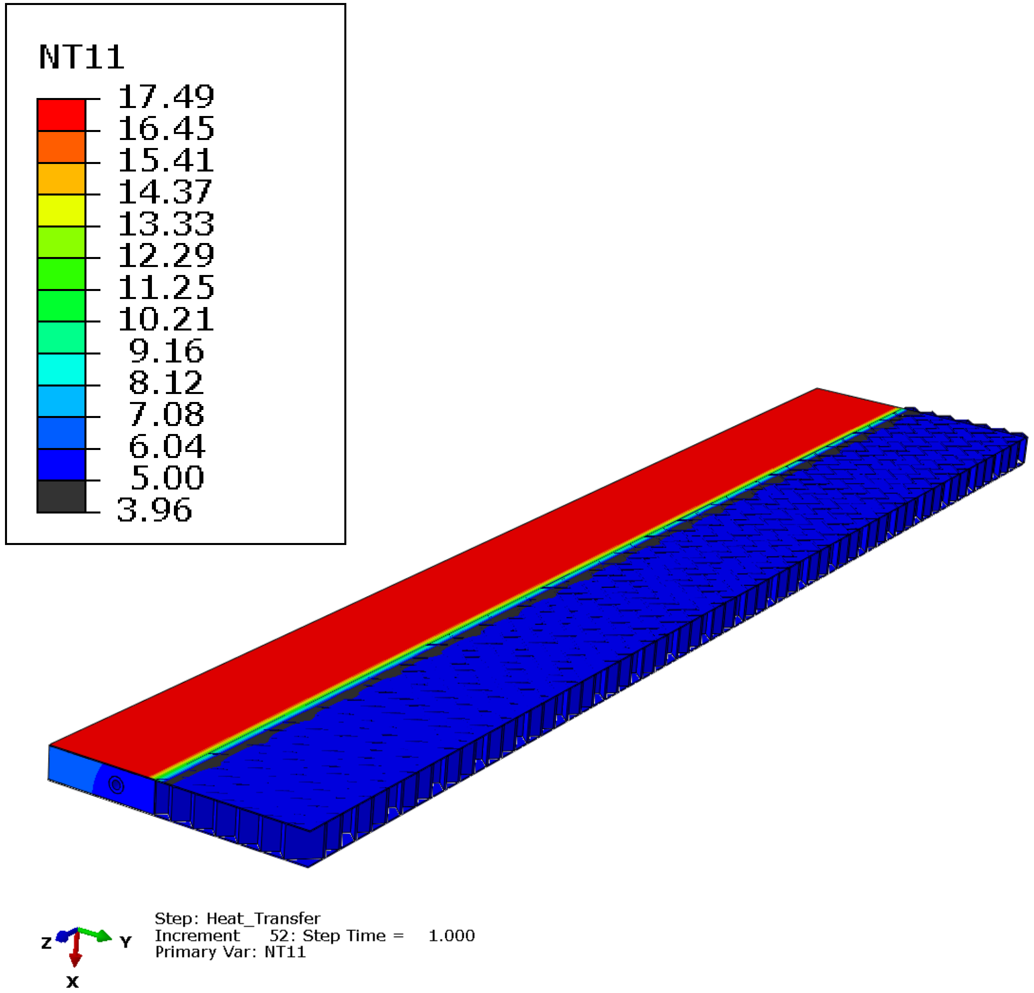
Study cure cycle for lowest peak strain in composites



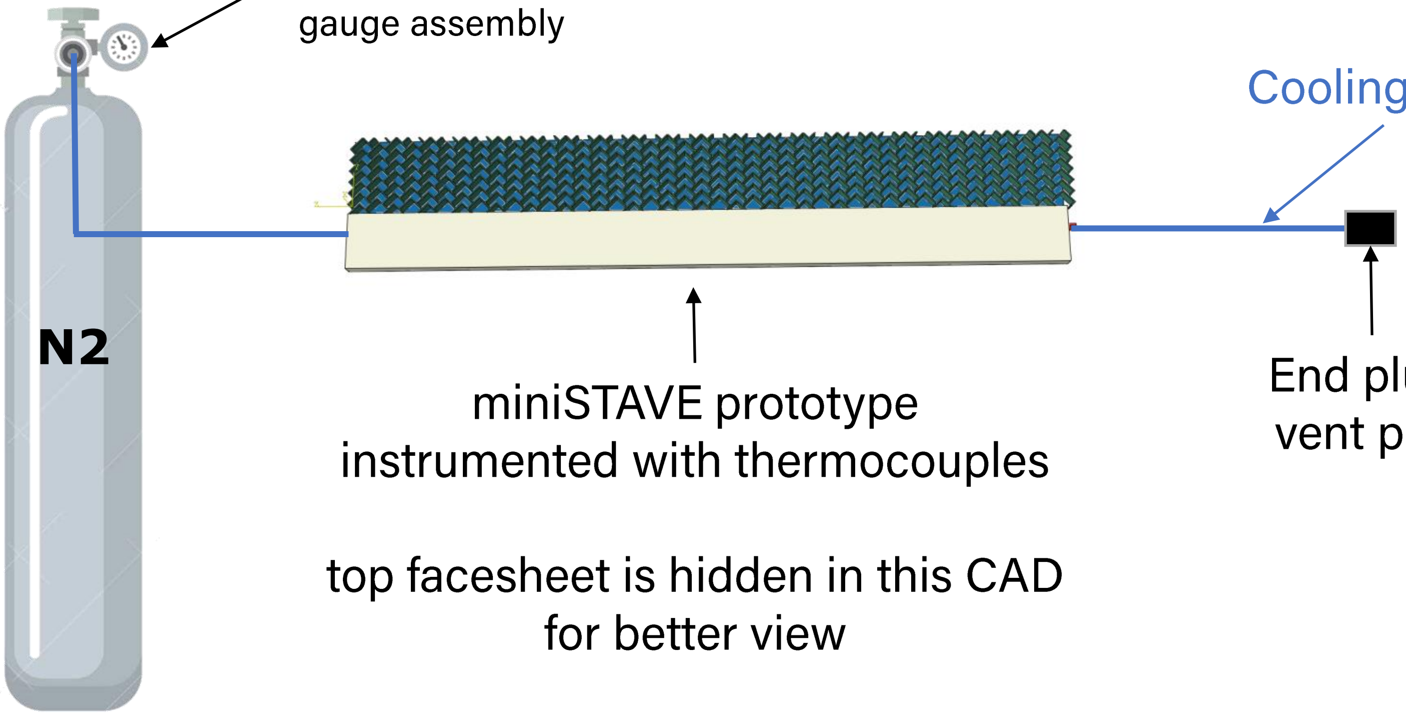
Initial Heat Transfer Results - miniSTAVE

- Convection to free air at ambient = 20 °C
- Radiation loss
- Glycol cooling through the pipe at 5 °C
- Heat transfer coefficients for the SS pipe used from CMS capillary results – need to change this to match the EIC – AC-LGADs set up
- Heat loads from Zhenyu's slide – 5.4W/cm2 on module
- $\Delta T = 12°C$ between coolant and sensor/ROCs
- Carbon Foam, Layup and honeycomb properties same as those that will be used for porotypes (mentioned in previous slides)

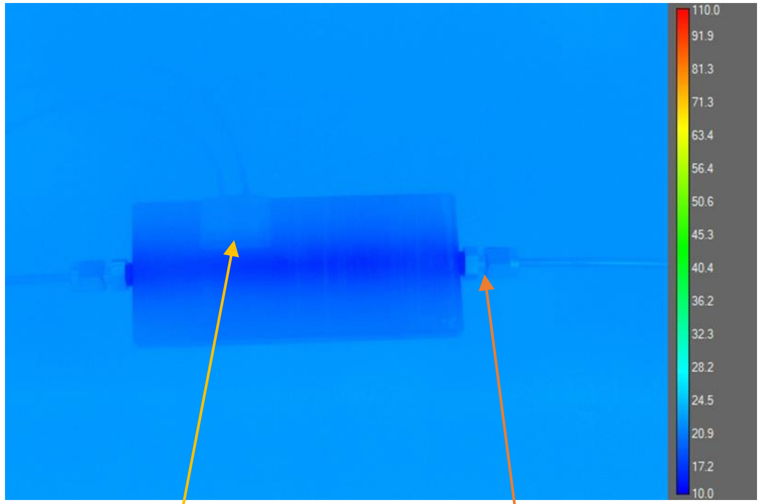
Unit: °C



Validation of the heat transfer analysis with testing and comparison to thermal-IR imaging with mock heaters



Picture from a different test / for representational purpose only!



Summary and Next steps

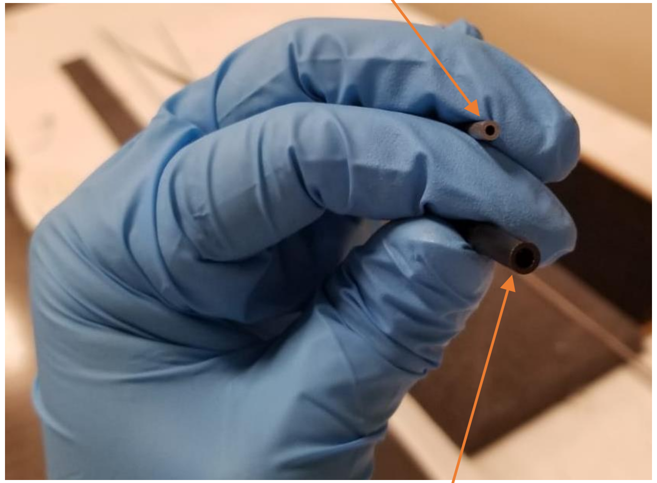
- First prototyping efforts well underway and promising.
- Deformations in the staves are well understood and will be minimized.

Upcoming tasks at Purdue –

1. Manufacture miniSTAVE (x2) – 1 retained at Purdue, 1 for NCKU
2. Manufacture halfSTAVE (x1)
3. Heat Transfer Analysis – miniSTAVE, halfSTAVE, fullSTAVE (see NCKU talks)
4. Thermal testing of miniSTAVE
5. Structural performance FEA and loading tests/validation – miniSTAVE, halfSTAVE

Future work – can potentially move to CFRP tube insert instead of SS or titanium – depending upon thermal performance – we have one such tube and we will evaluate the same with a miniSTAVE prototype

SS304 tube



CFRP tube