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Modelling of Core Crush Phenomenon
during the Processing of Honeycomb
Sandwich Panels





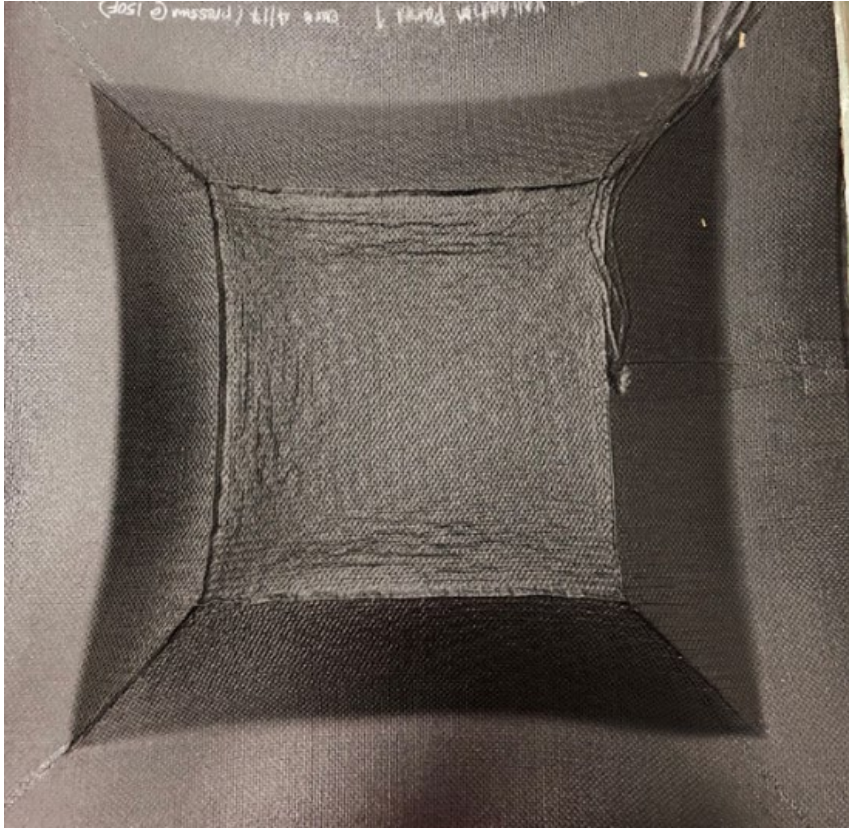
Modelling of Core Crush Phenomenon during the Processing of Honeycomb Sandwich Panels

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Tara Baker, Marta Elleby, The Boeing Company

Outline

- Background and objective
- Material characterization
- Modelling approach
- Results
- Conclusion

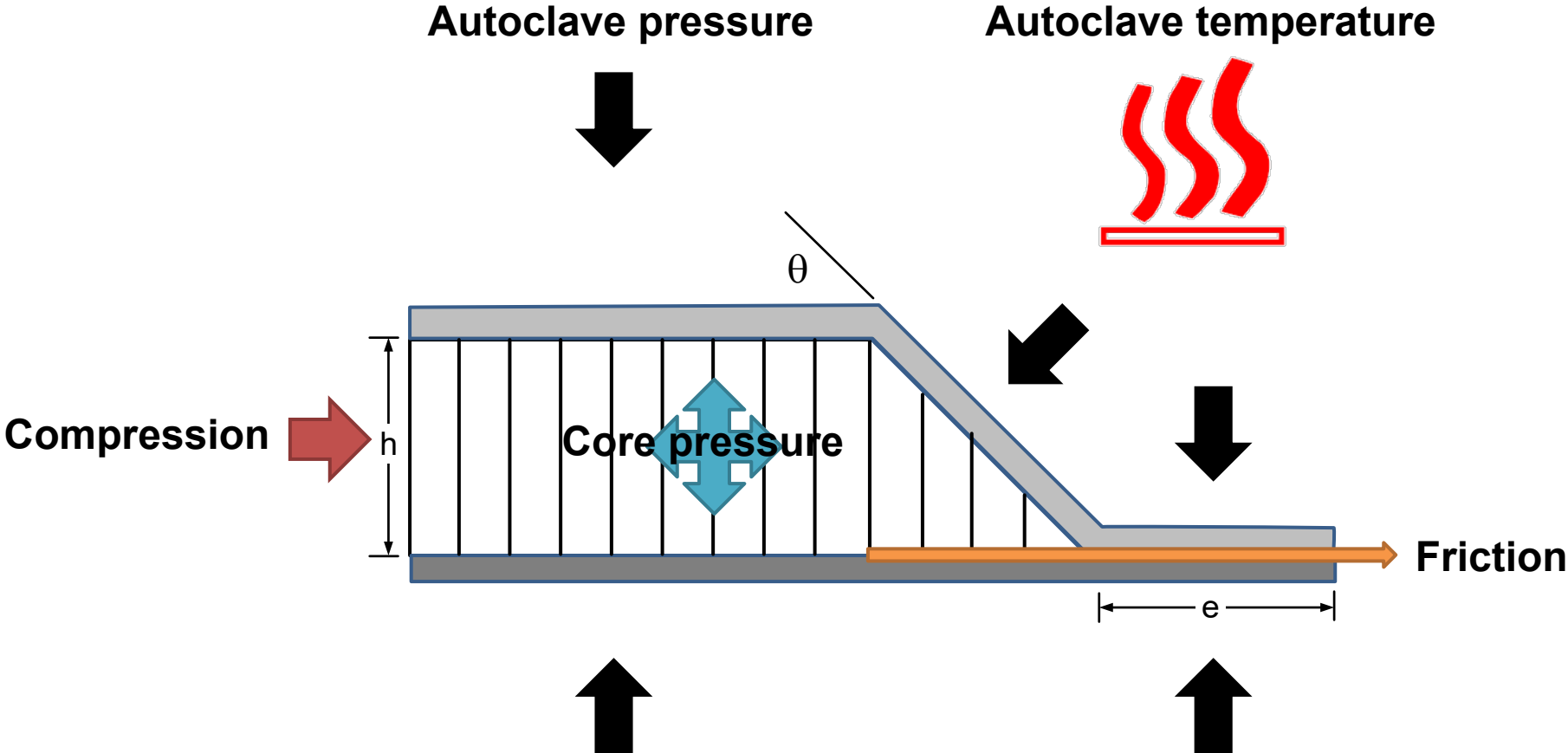
Core crush (1/2)



Core crush main factors:

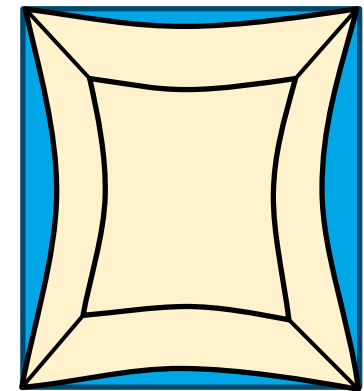
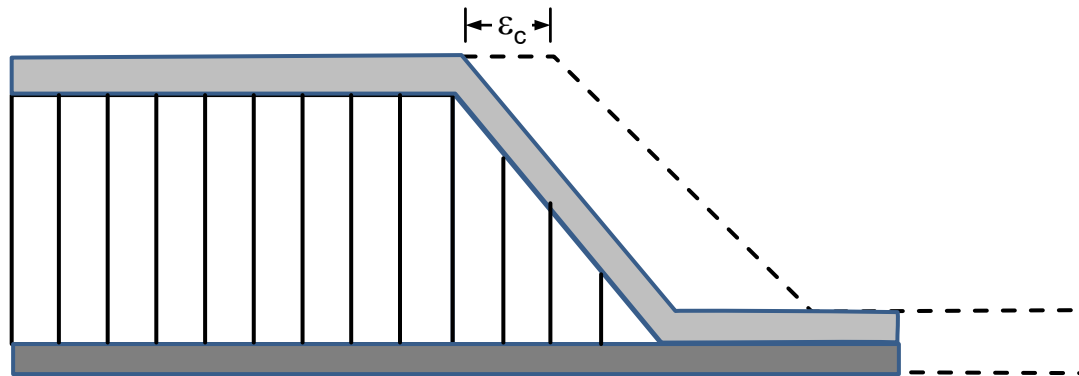
- Prepreg, adhesive and core properties
- Panel geometry
- Bagging conditions
- Cure cycle

Core crush (2/2)



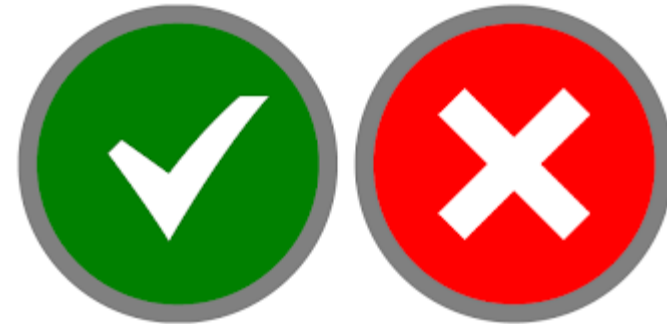
Core crush (3/3)

$$\% \text{ crush} = \frac{\text{crushed core area}}{\text{initial core area}}$$



Objective

- Develop a model for sandwich panel core crush during manufacturing as a function of:
 - part geometry
 - materials
 - bagging
 - cure conditions

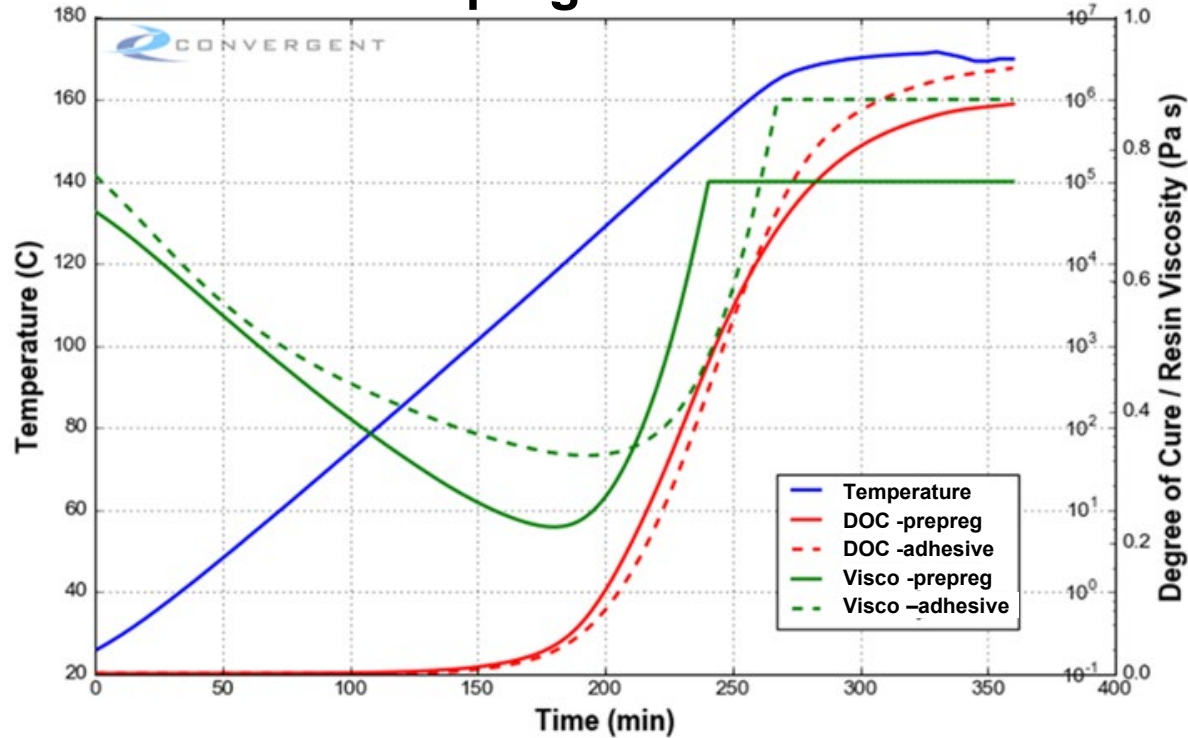


Materials

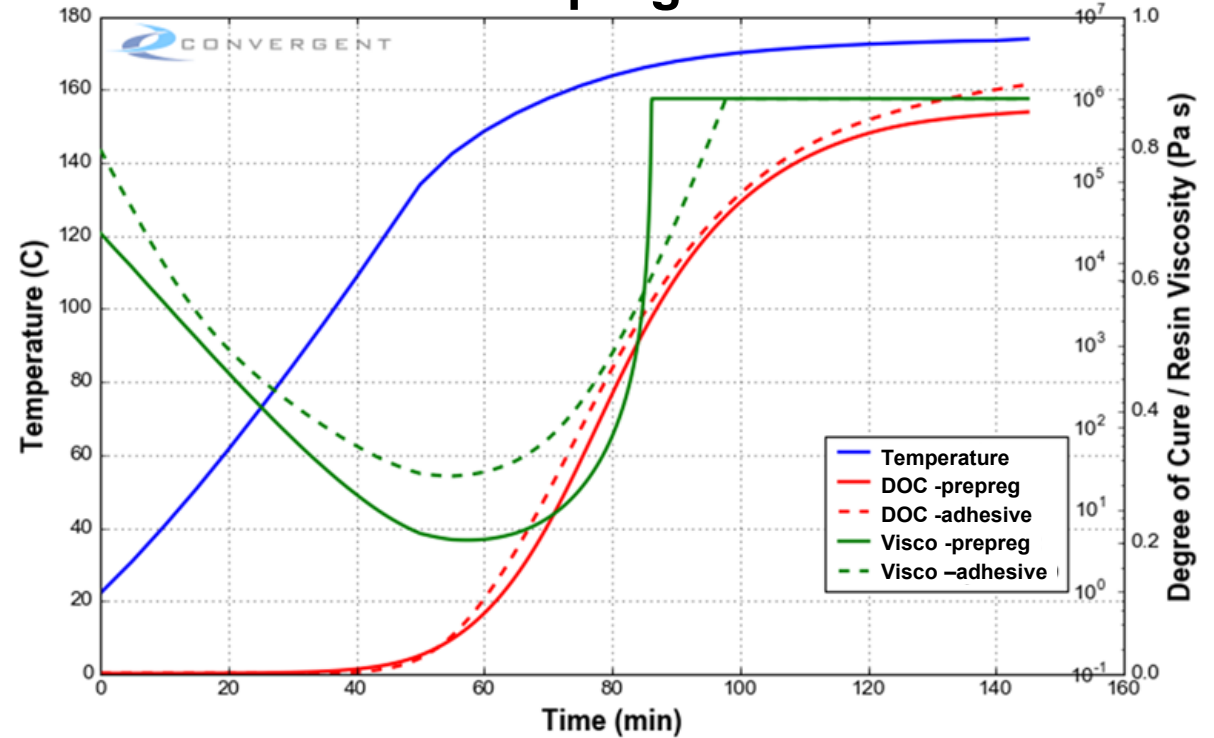
- Prepregs:
 - autoclave carbon fibre epoxy (prepreg A)
 - out of autoclave capable carbon fiber epoxy (prepreg B)
- Adhesive:
 - film adhesive
- Core:
 - Nomex 3.175 mm cell size (N1)
 - Nomex 9.525 mm cell size (N3)

Resin properties

Prepreg A



Prepreg B

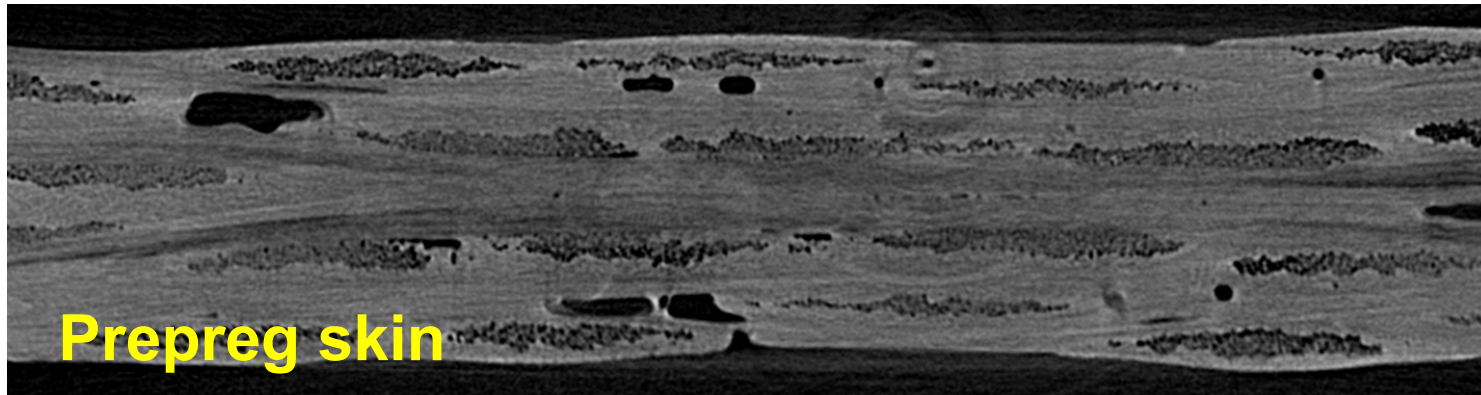


**DOC
Viscosity**

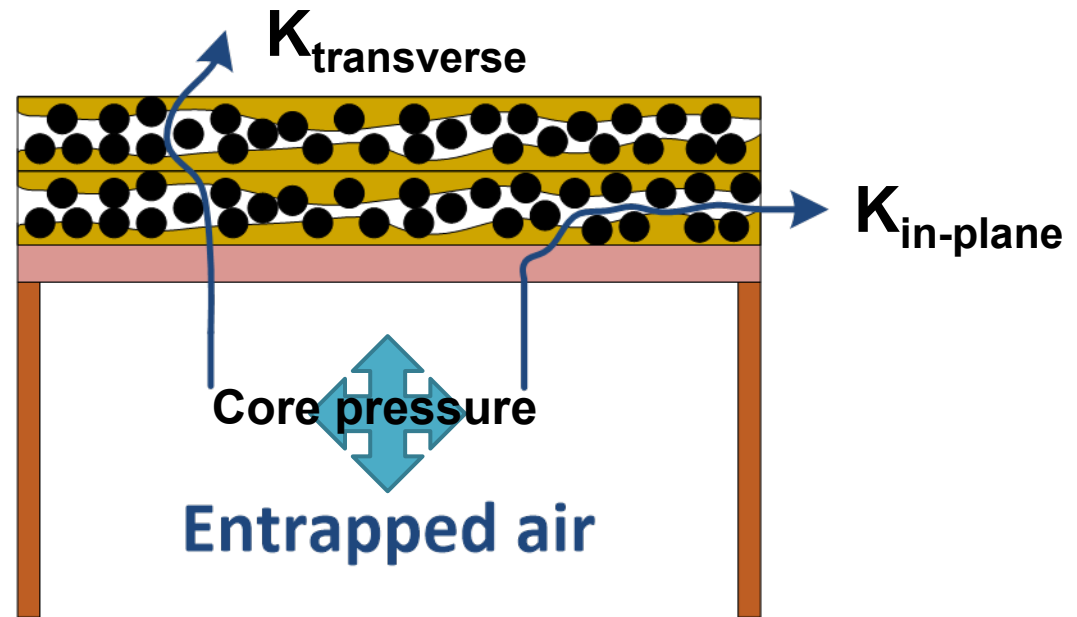


**Skin stiffness
Skin-core friction**

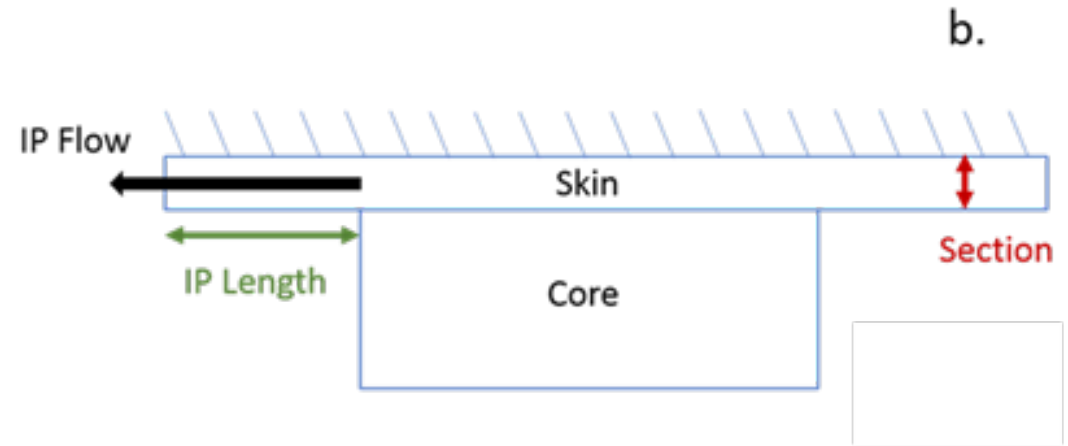
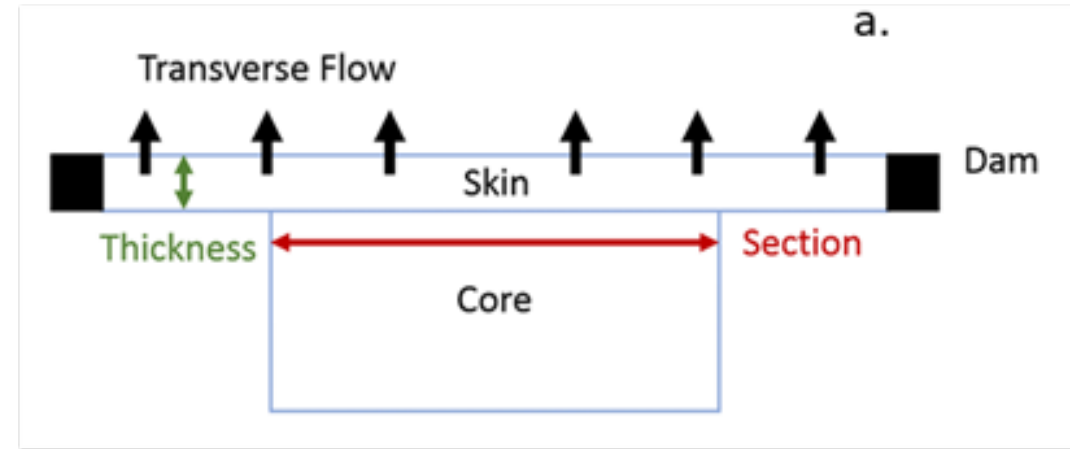
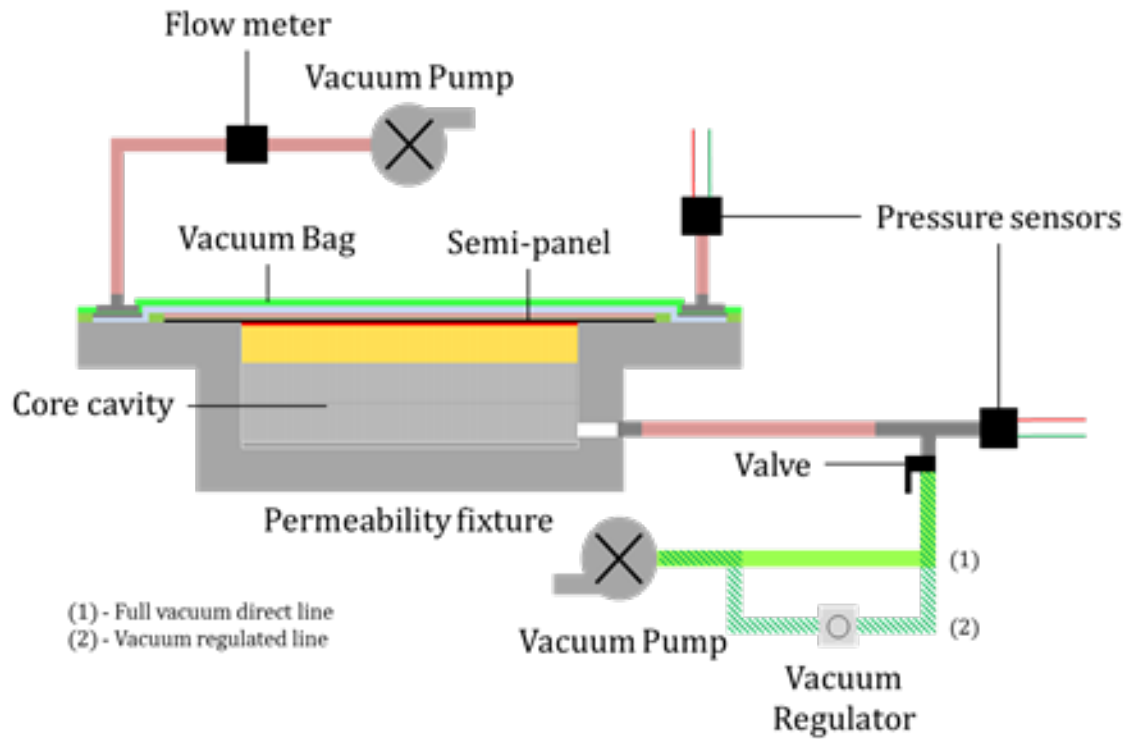
Skin air permeability (1/3)



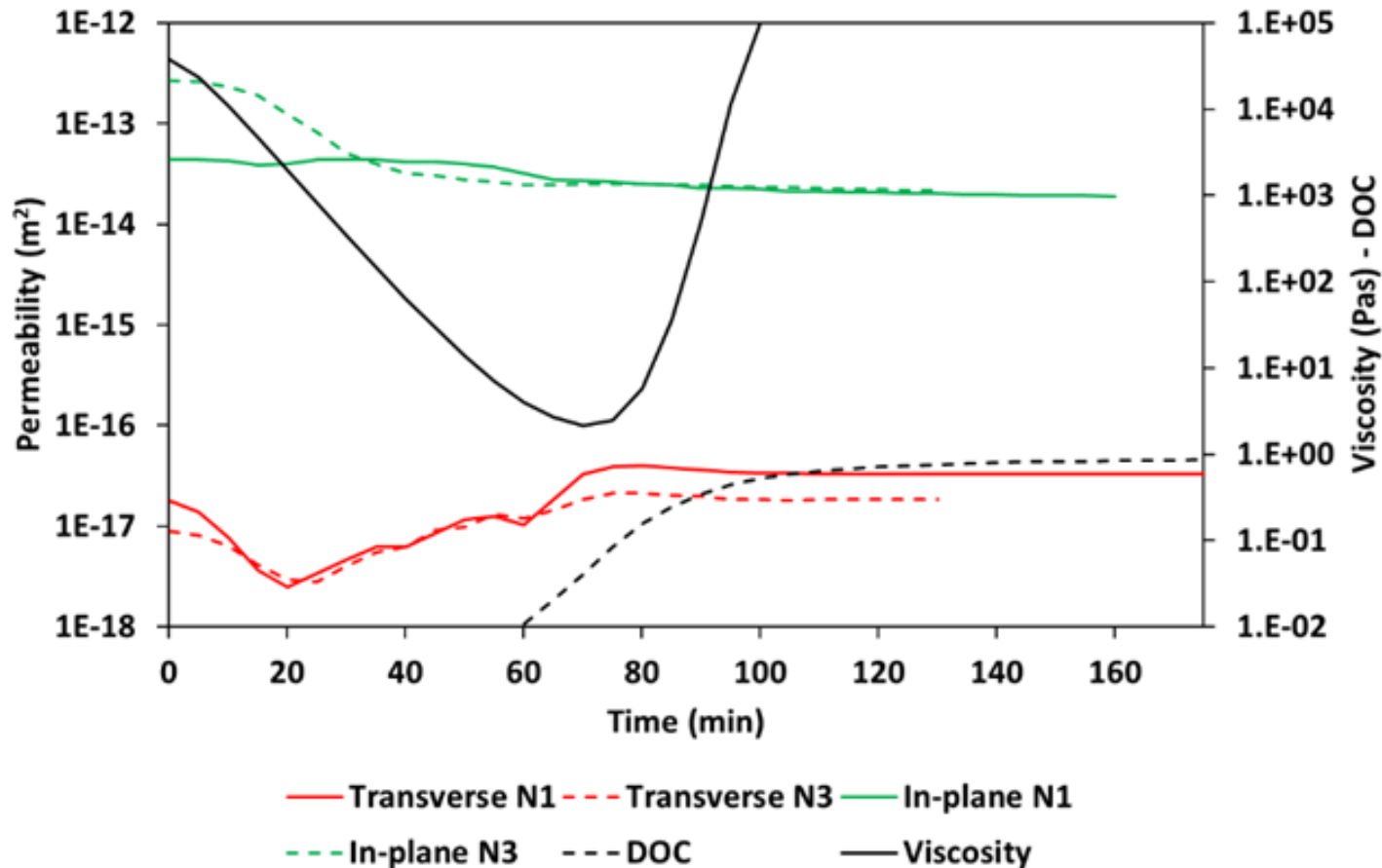
- Effect on core pressure
 - Temperature
 - Moisture
 - Skin permeability



Skin air permeability (2/3)



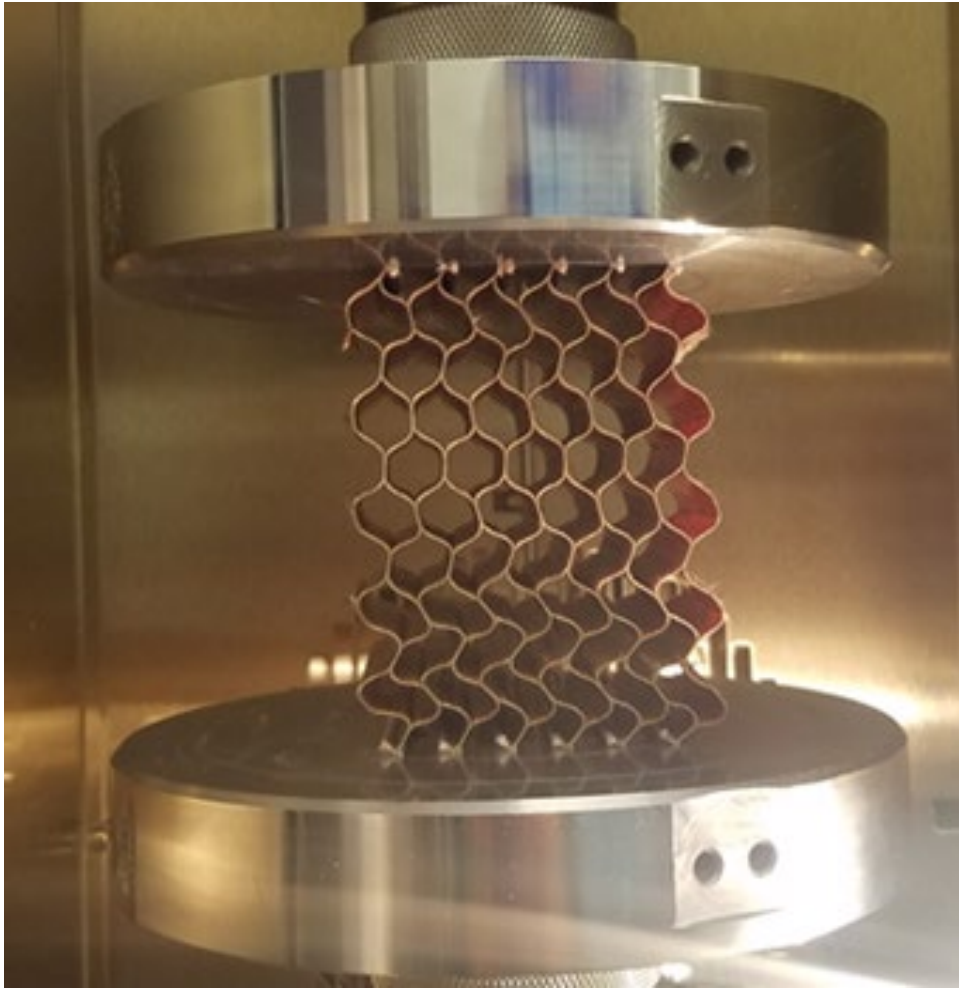
Skin air permeability (3/3)



Effect investigated:

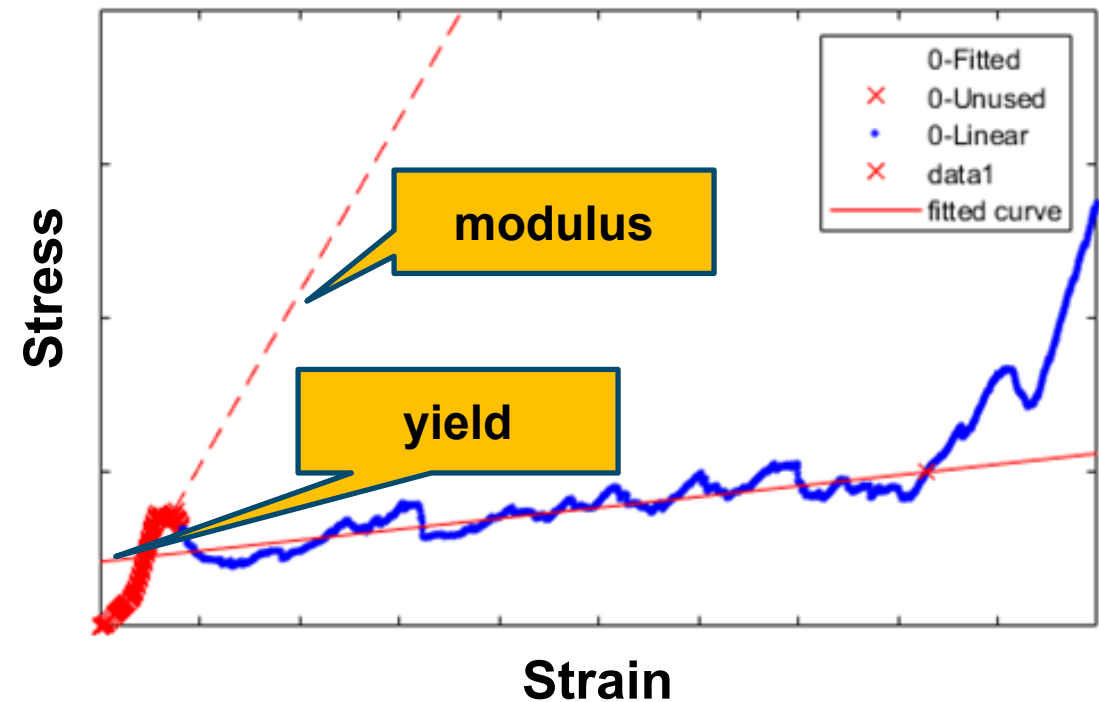
- honeycomb cell size
- skin thickness
- cure cycle
- AFP compaction pressure

Core compression



Effect investigated:

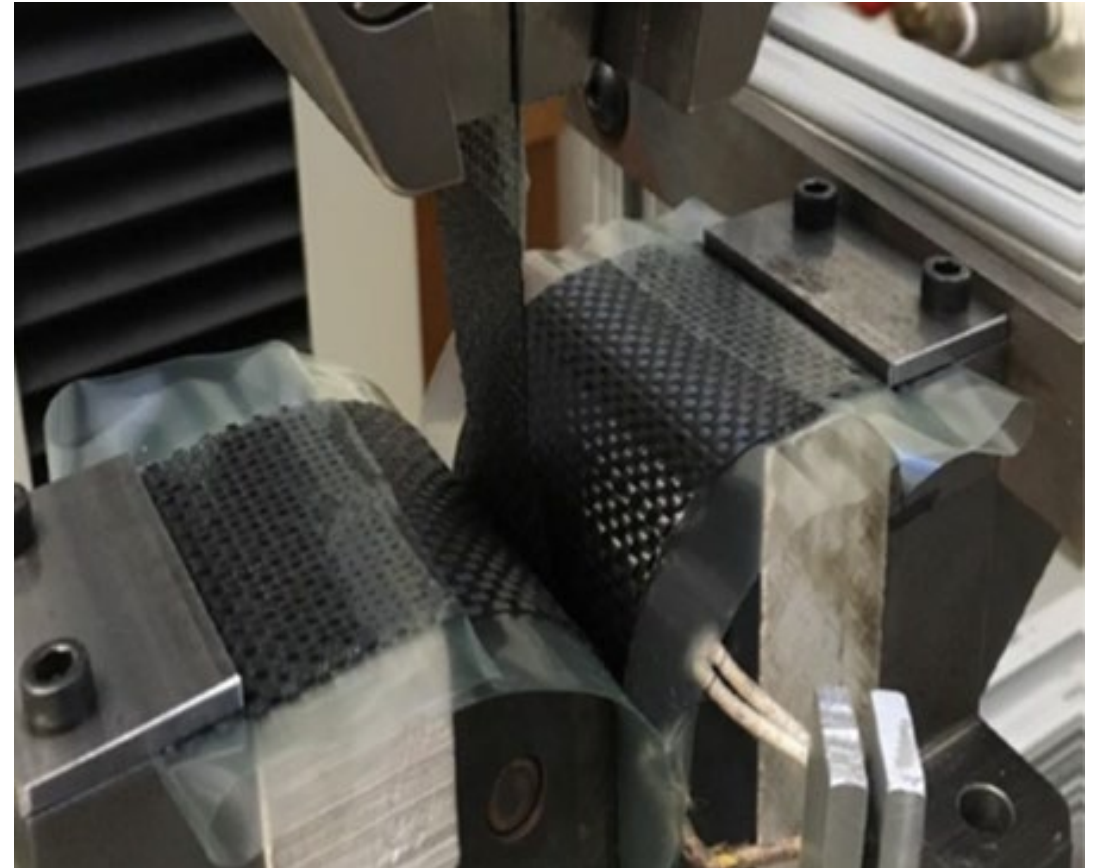
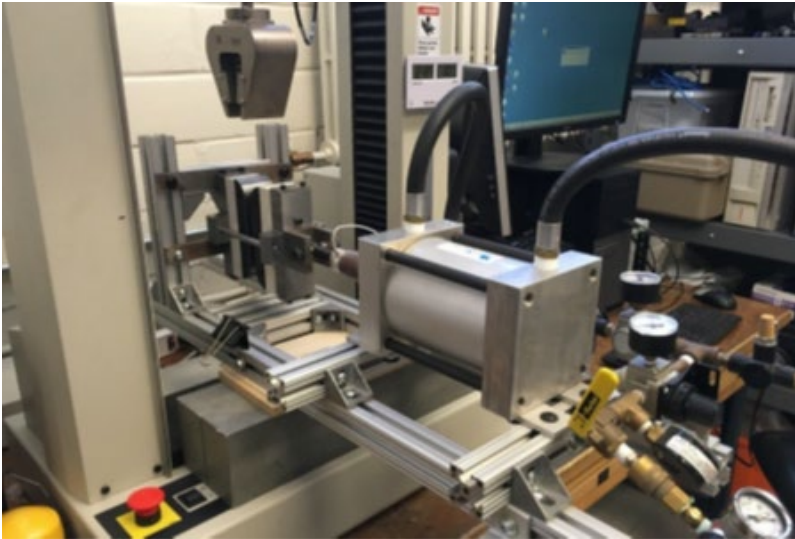
- cell size
- direction
- thickness
- stabilization



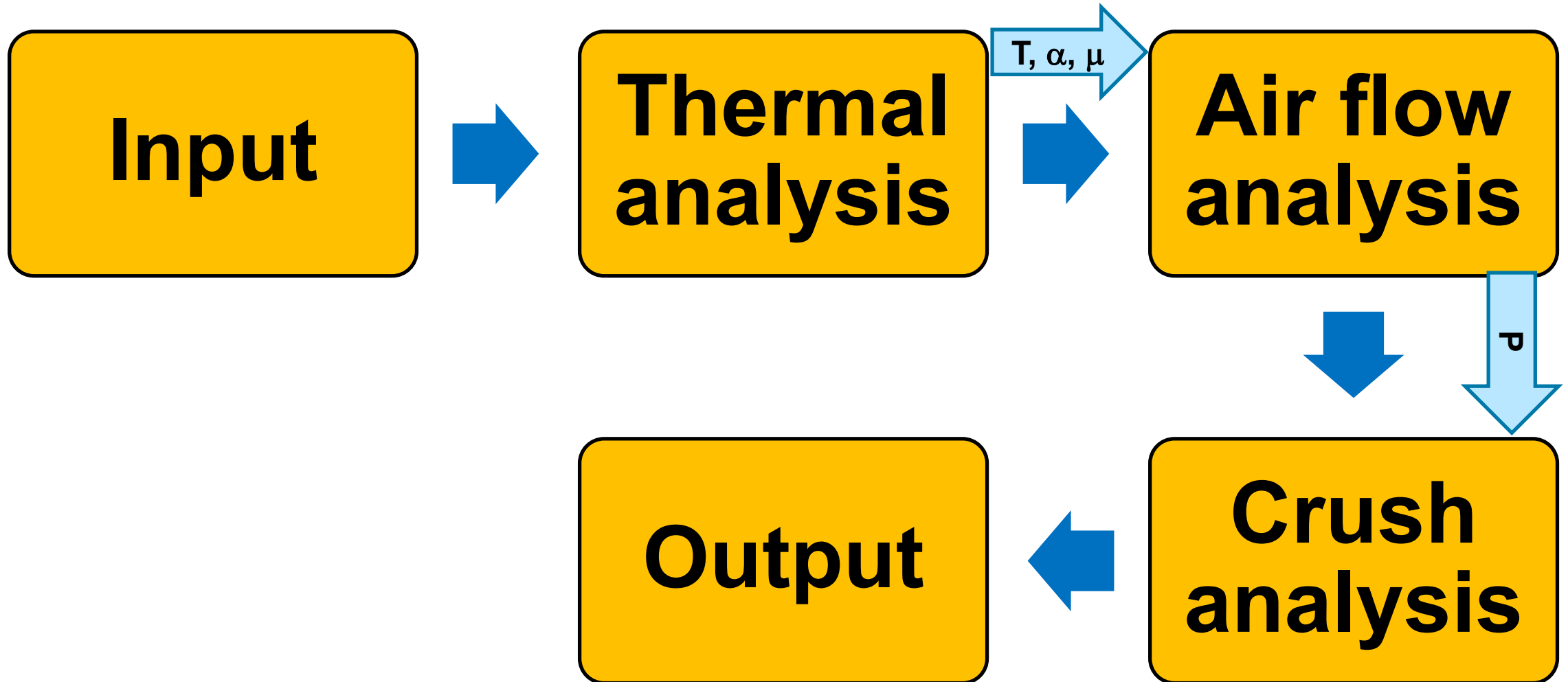
Skin friction

Effect investigated:

- temperature



Model architecture



Core pressure simulation (1/2)

1) Nominal conditions:

Initial core pressure: 5kPa

Initial core moisture content: 0.5%

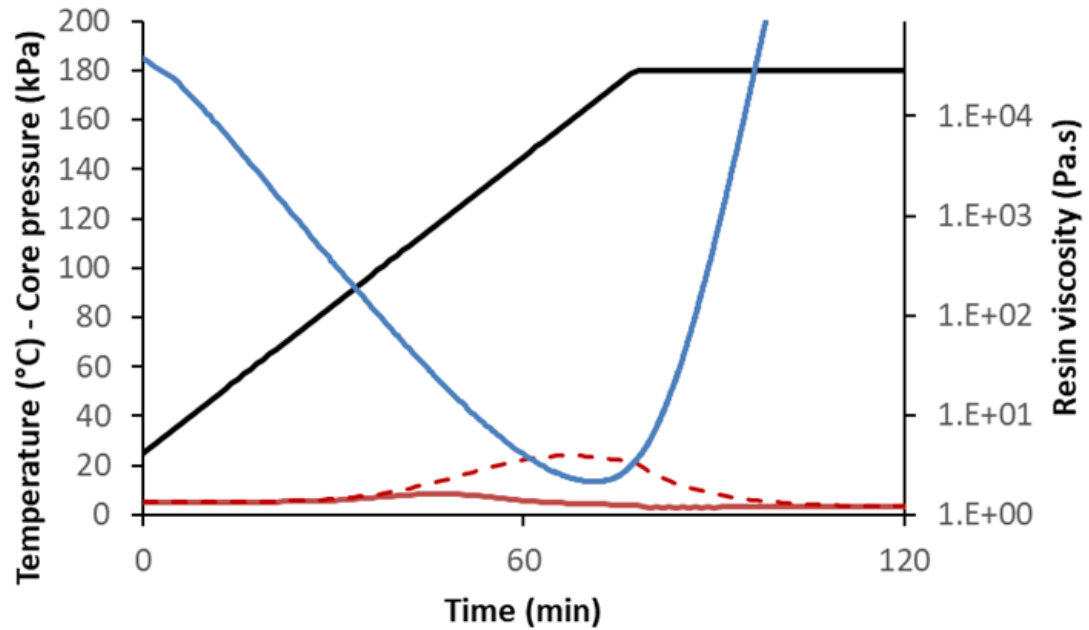
2) Severe conditions:

Initial core pressure: 50kPa

Initial core moisture content: 4%

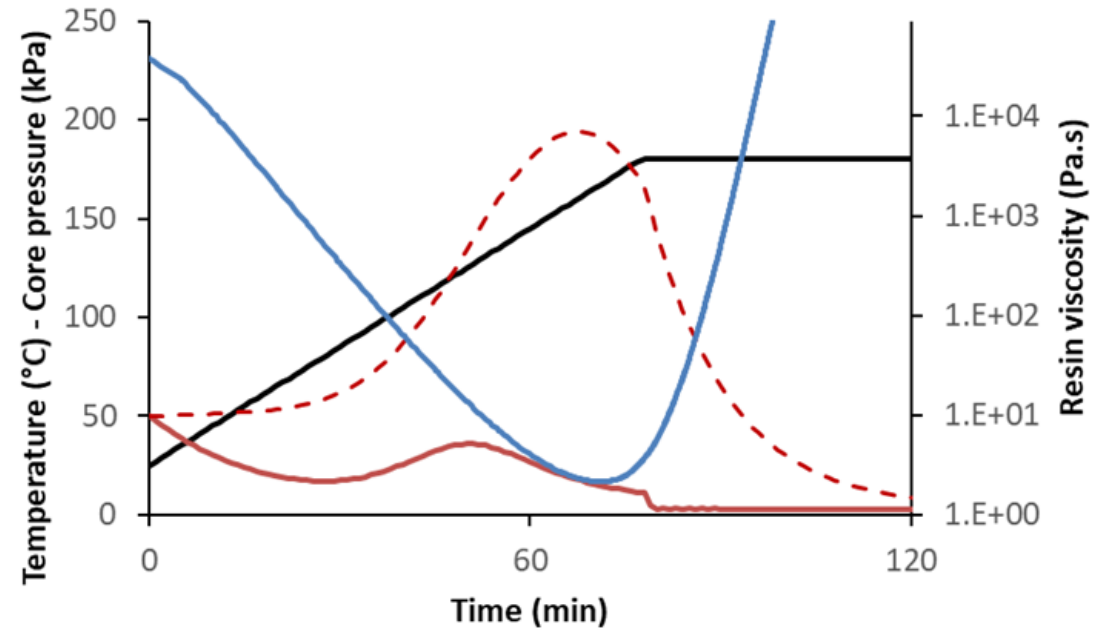
Core pressure simulation (2/2)

Nominal



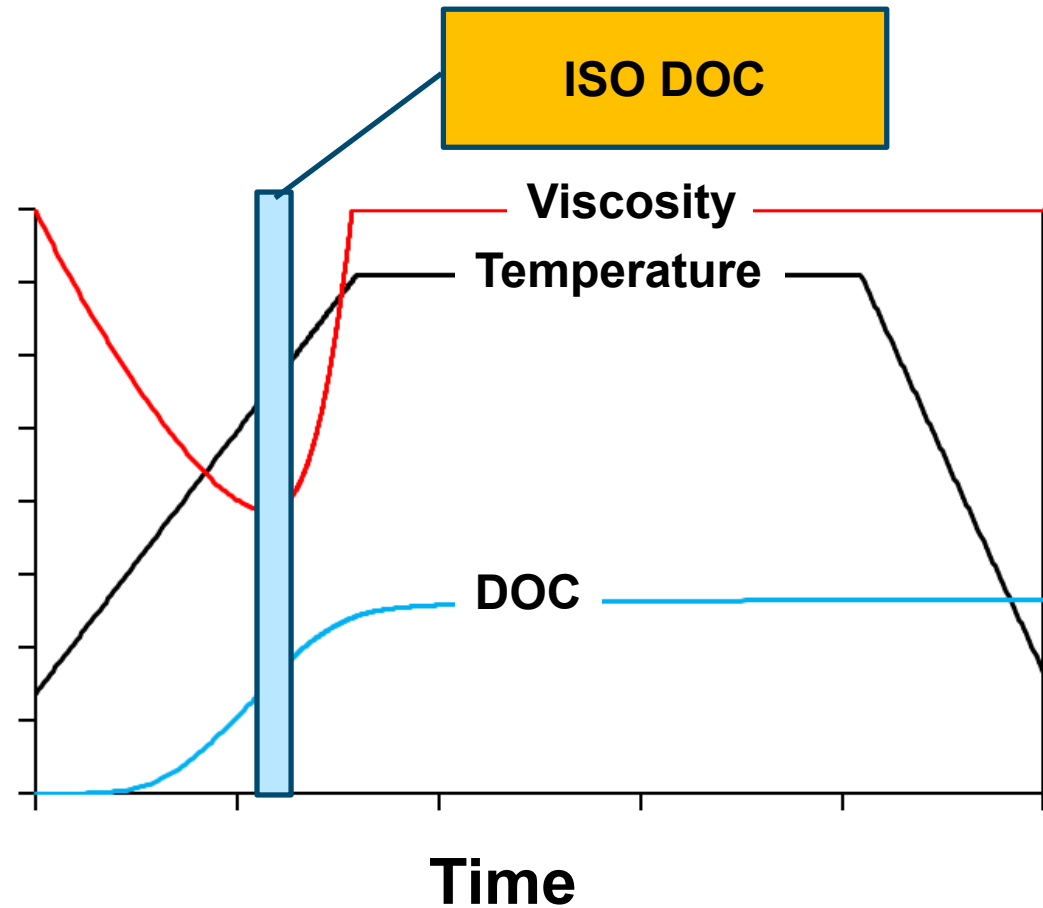
— Temperature — Core pressure - transverse
- - - Core pressure - in-plane — Viscosity

Severe

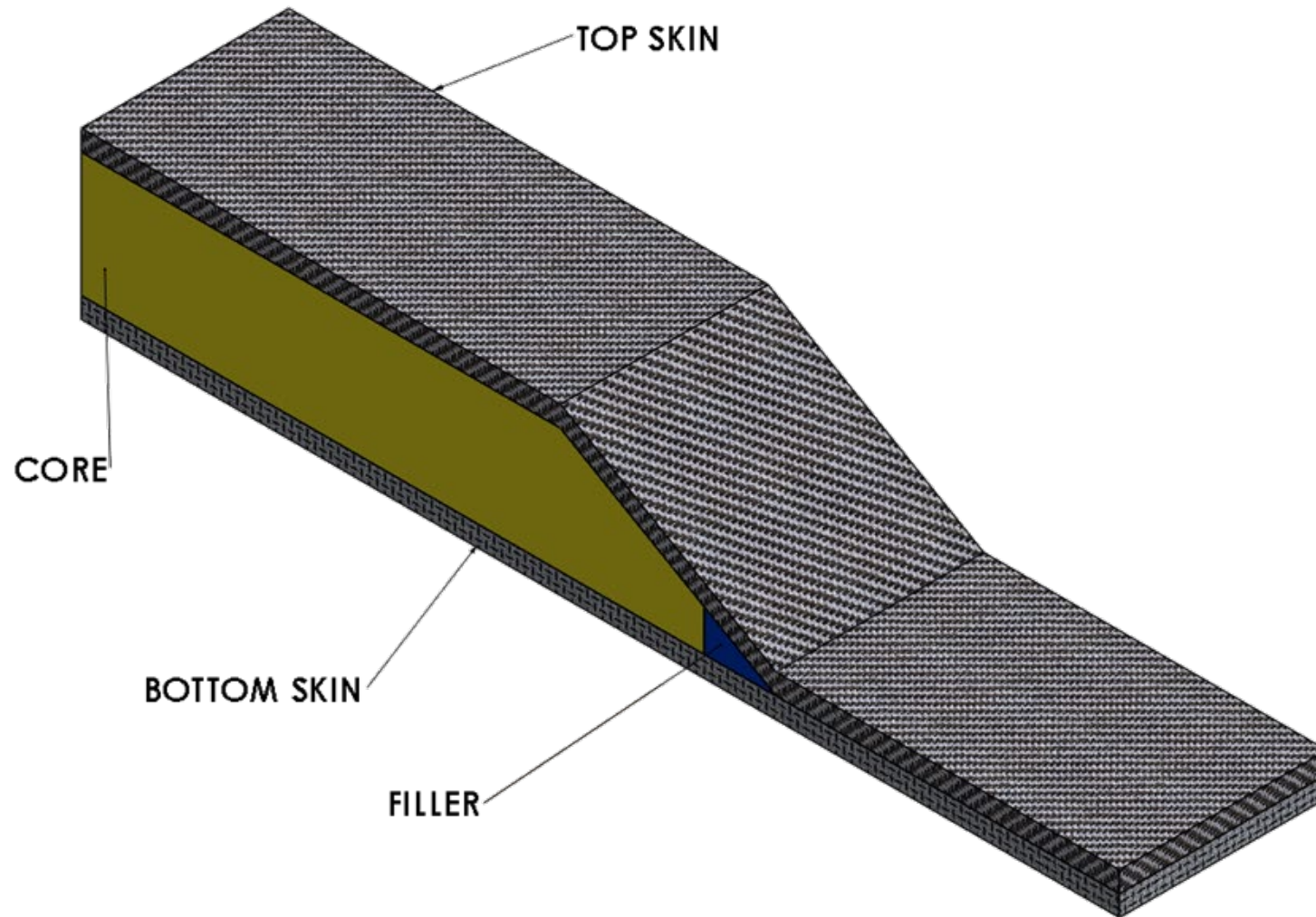


— Temperature — Core pressure - transverse
- - - Core pressure - in-plane — Viscosity

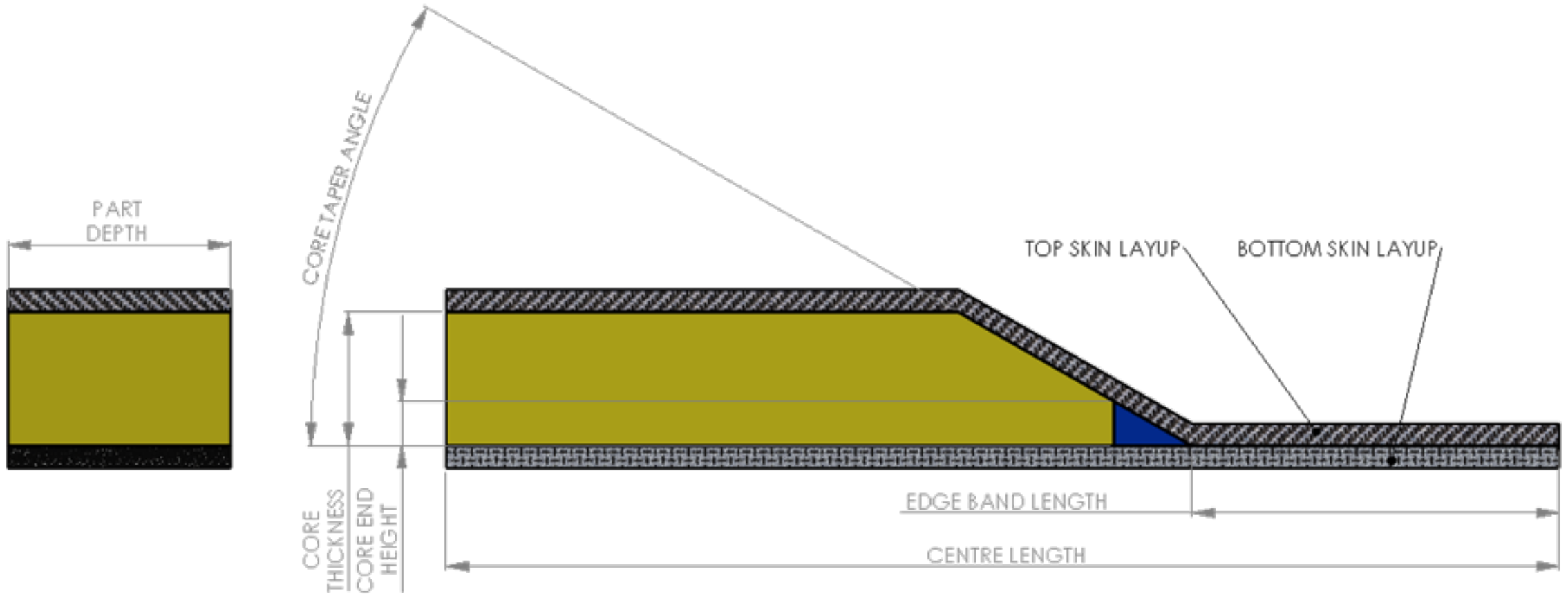
DOC input for core crush simulation



Model components

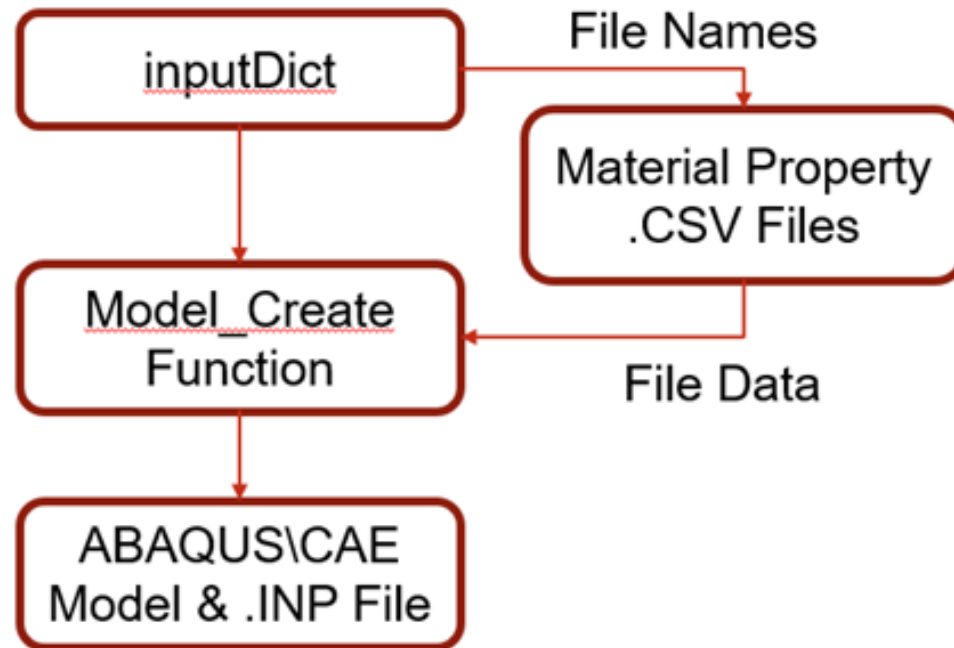


Model parameters

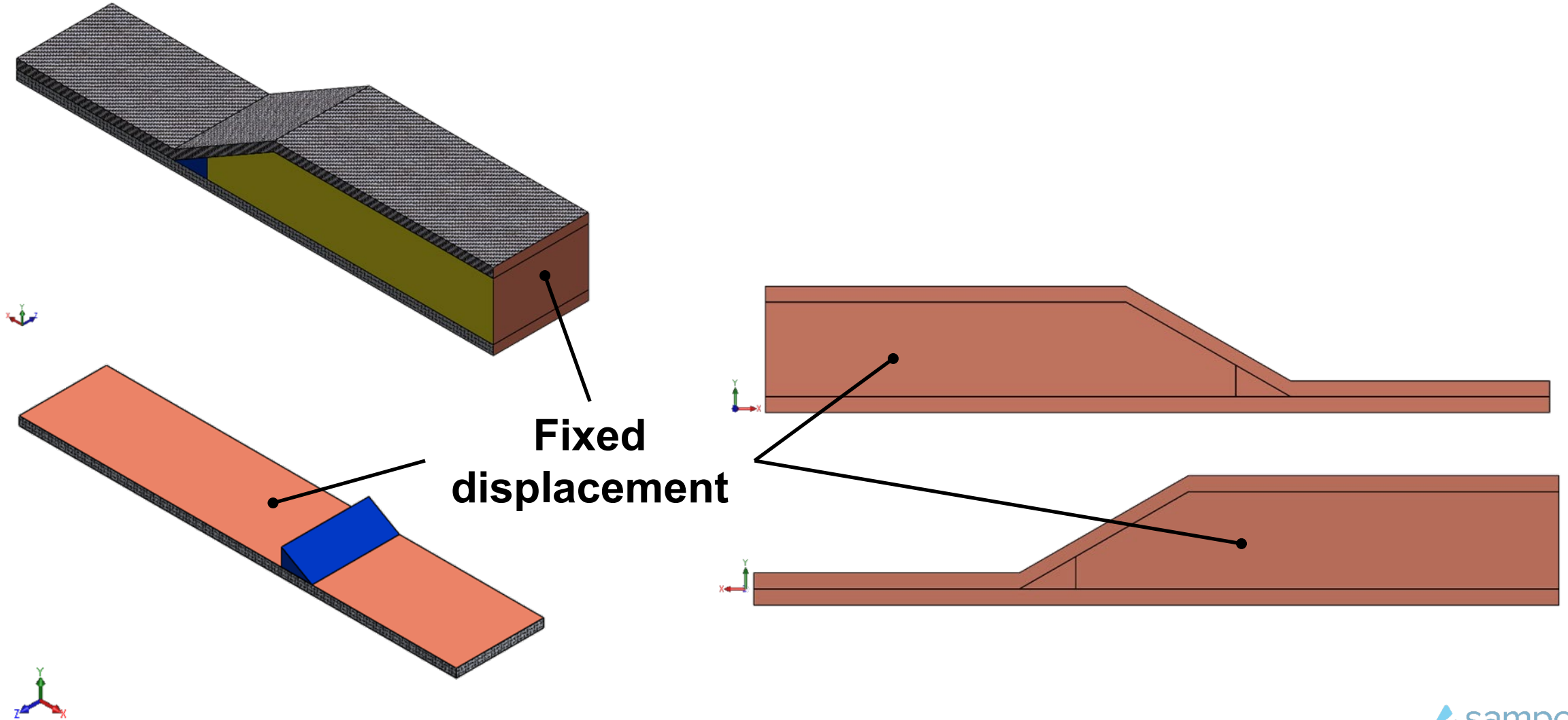


Model workflow

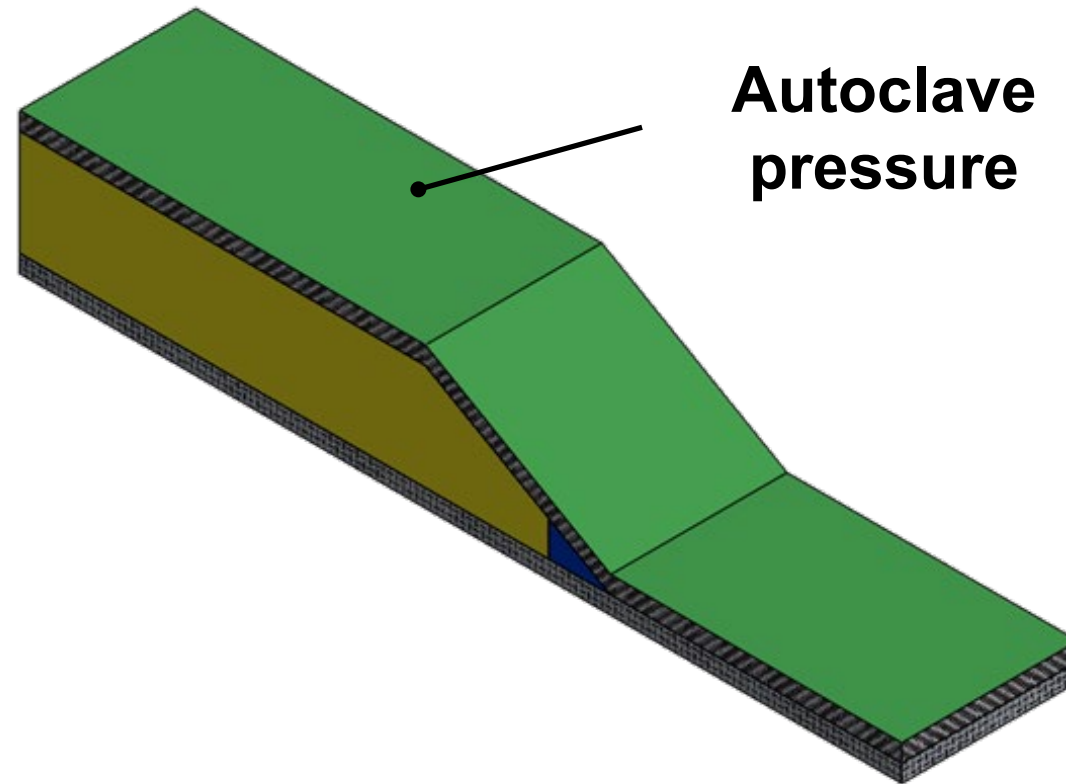
- Abaqus solver
- C3D8HS linear brick elements with hybrid formulation



Boundary Conditions



Loads



Material properties and interactions

- Core:
 - From core compression test data
- Skin material properties:
 - Young's modulus : 5 [GPa]
- Skin-skin friction:
 - From friction test data
- Skin-core friction:
 - No stiffness in the out-of-plane direction
 - Small Sliding contact pressure and temperature independent friction coefficient

Core crush criteria

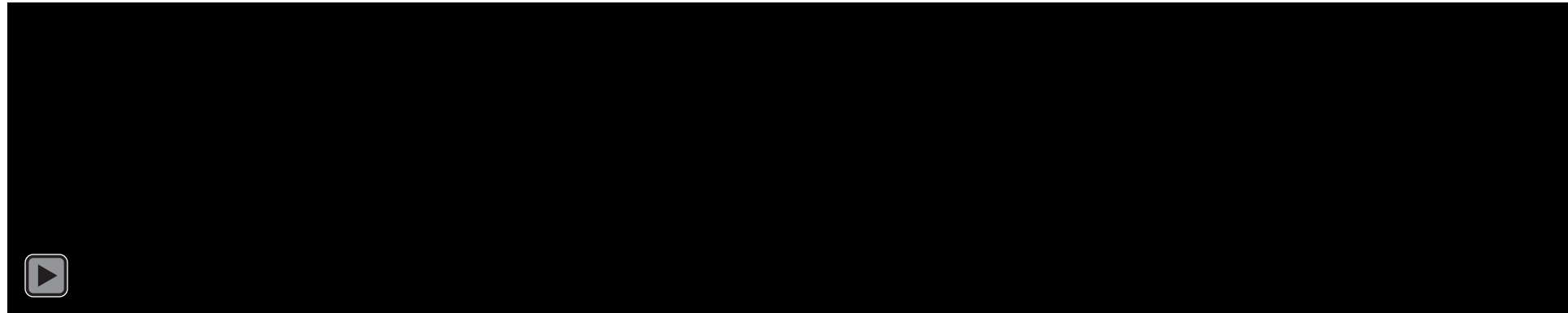
- Core yield stress
- Core compressive stress

$$SF_{Mean} = \frac{\sigma_{Yield}}{\sigma_{11, Mean, Taper}}$$

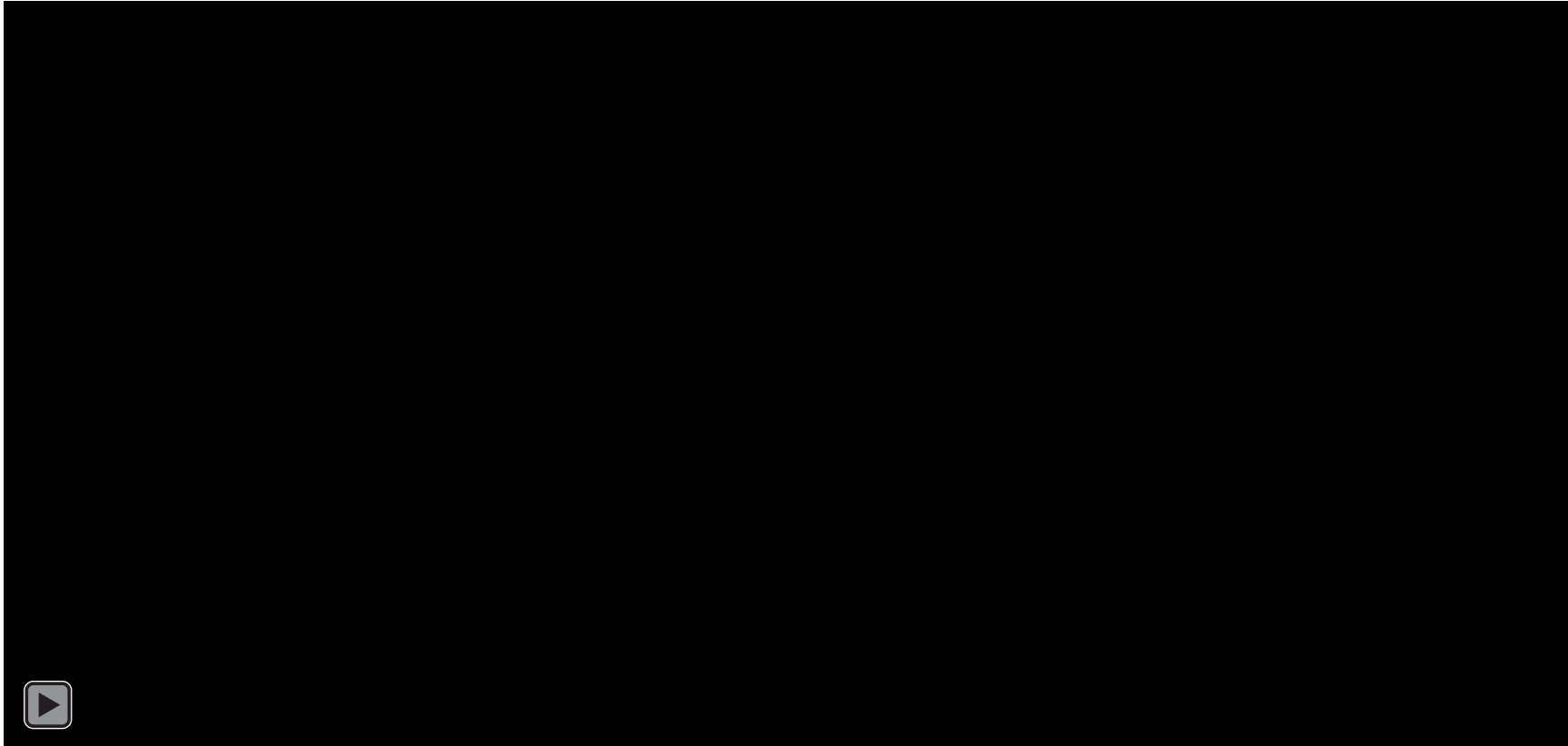
$$SF_{max} = \frac{\sigma_{Yield}}{\sigma_{11, Max Compressive, Core}}$$

$\left\{ \begin{array}{l} \text{Crush if } SF < SF_{Target} \\ \text{No Crush if } SF > SF_{Target} \end{array} \right. \rightarrow \text{Typical } SF_{Target} = 1$

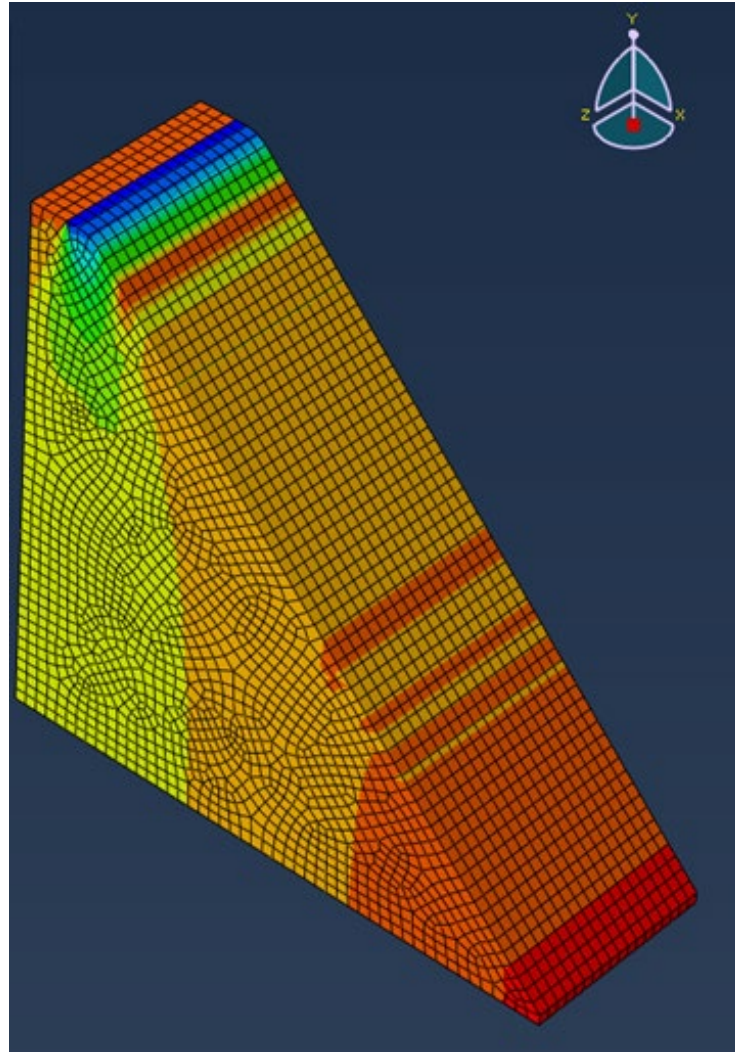
Sample Case – Unstabilized w/ Crush



Sample Case – Unstabilized w/ Crush

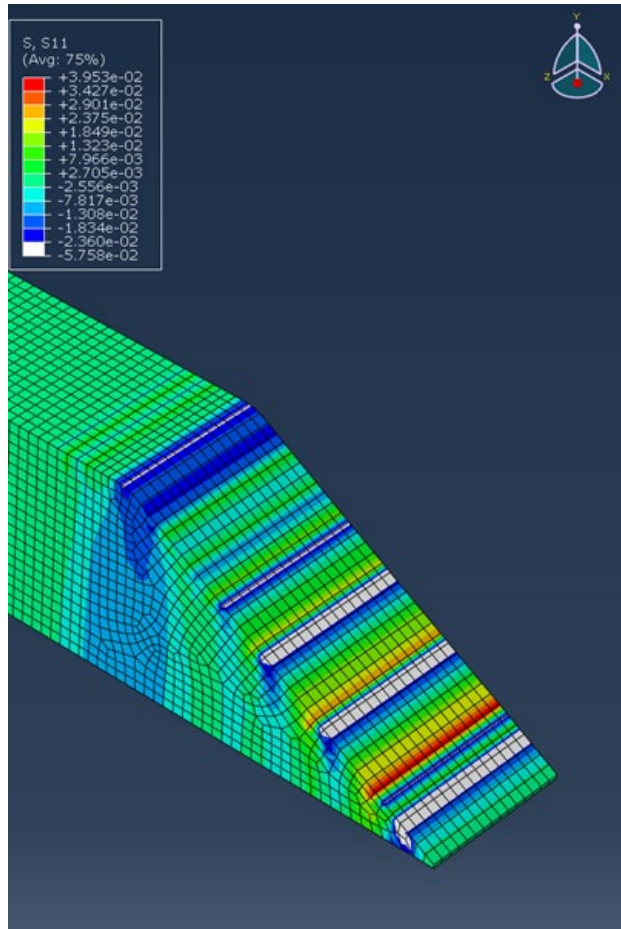


Taper region - mean stress

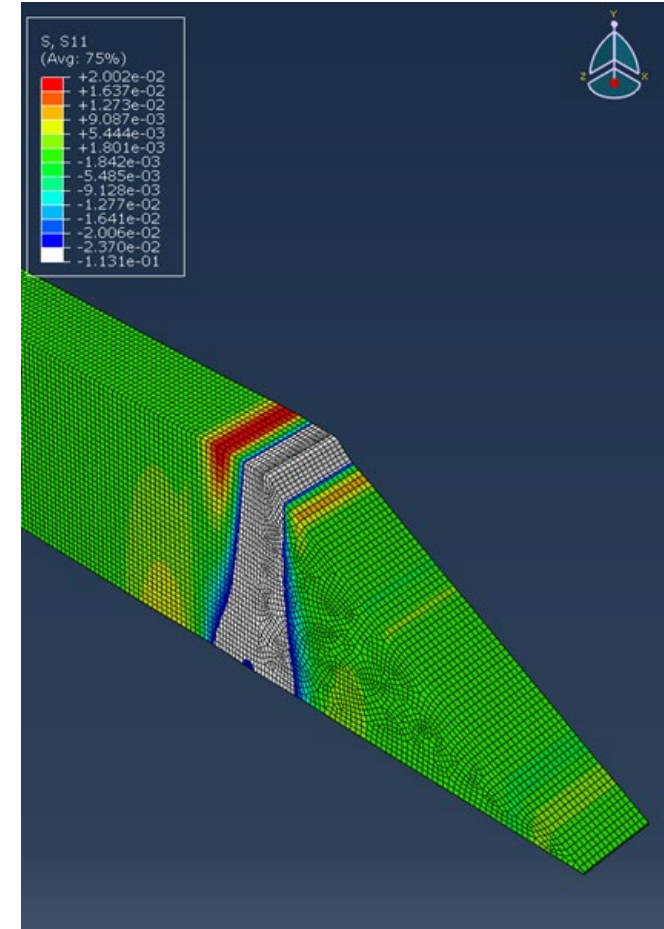


Core crush results

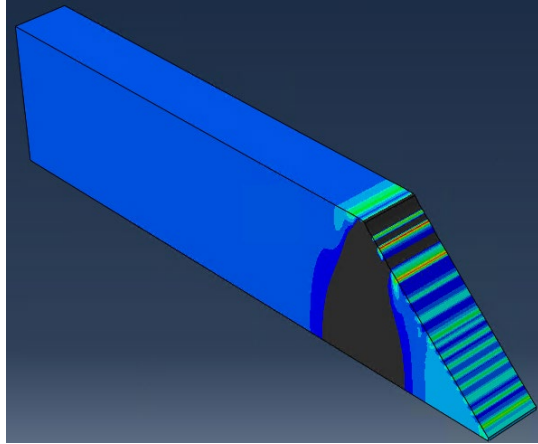
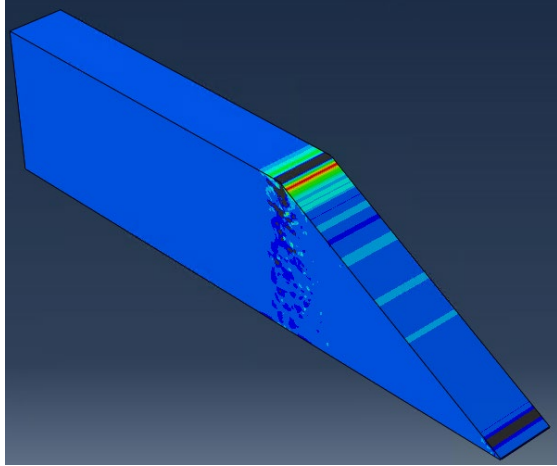
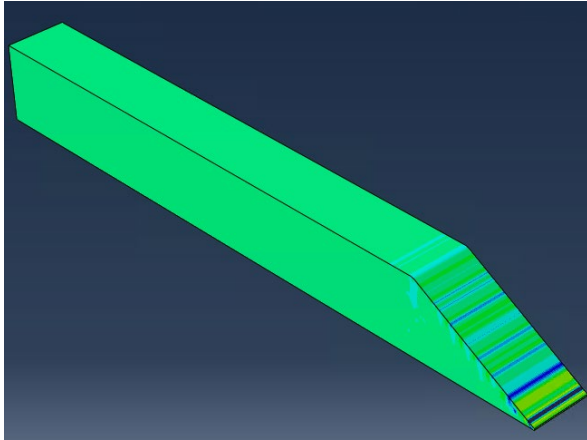
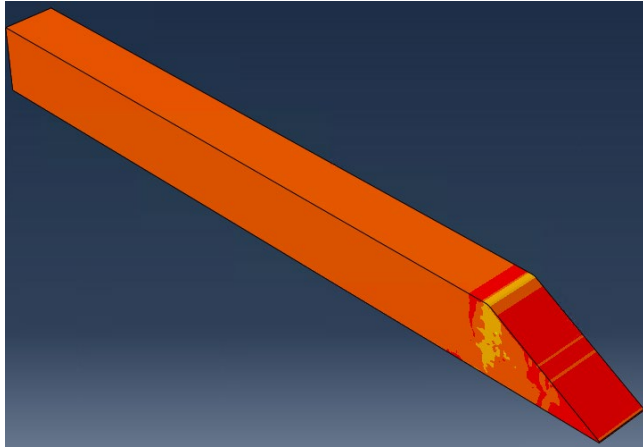
Local core crush



Global core crush



Sample Case – Stabilized w/ Crush

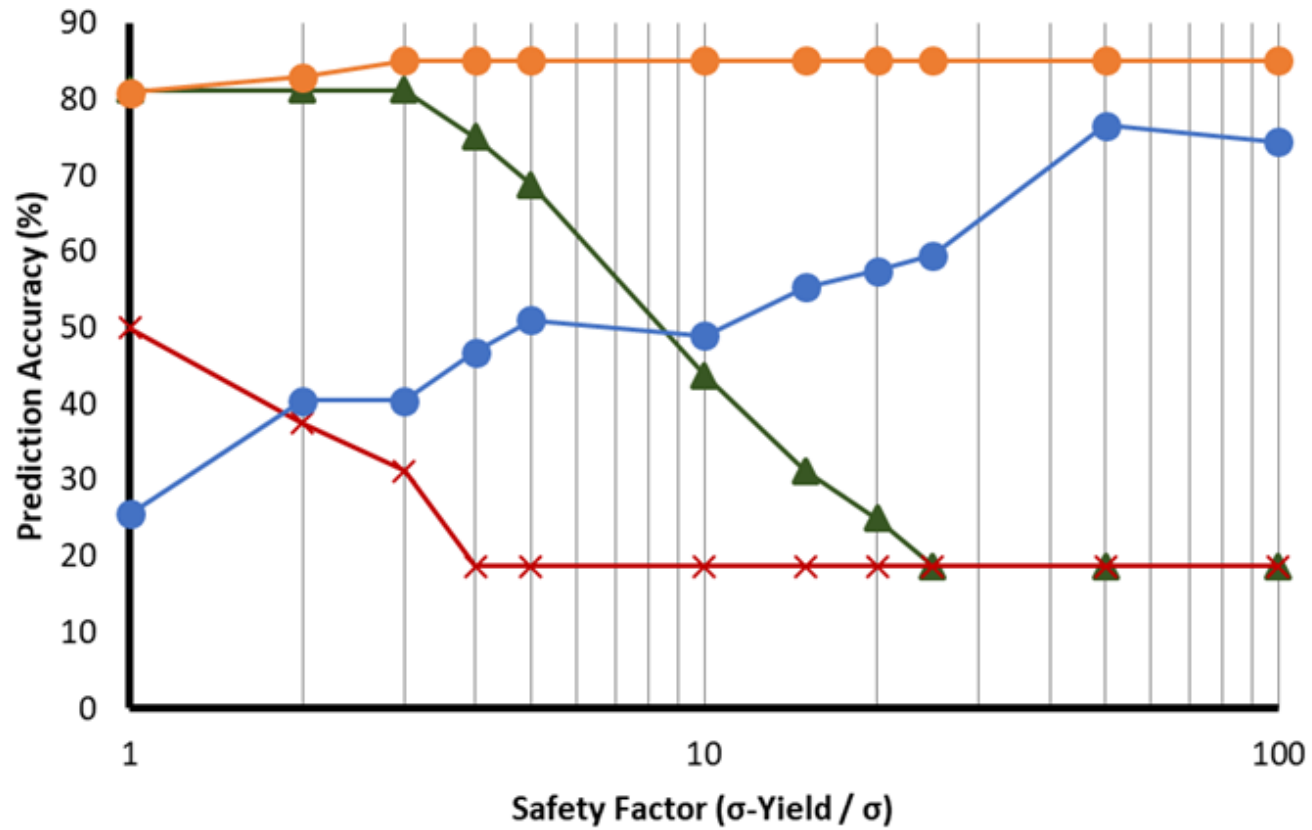
	Unstabilized	Stabilized
Crush		
No Crush		

Effects considered

	Experiment	Model
Chamfer angle	✓	✓
Core thickness	✓	✓
Cure pressure	✓	✓
Stabilization	✓	✓
Cell size	✓	
Skin thickness	✓	
Edge band width	✓	✓
Bag vent speed	✓	
Cure ramp rate	✓	

Model accuracy

$$Accuracy = \frac{\# \text{ of Correct Predictions}}{\# \text{ of Tests}} * 100\%$$



▲ Stab-Mean-Stress ✕ Stab-Max-Stress
● Unstab-Mean-Stress ● Unstab-Max-Stress

Conclusion

- Honeycomb core in-plane compression was measured:
 - stabilization increases modulus by two orders of magnitude
 - stabilization increases yield by one order of magnitude
- A core pressure model was used to estimate the core pressure during cure:
 - core peak pressure was below 30 kPa in good core evacuation and low moisture content
- A FEA core crush model was developed with a prediction accuracy of 81%

Acknowledgments

- Boeing for this project with NASA under award No. NNL09AA00A through a sub award from the National Institute of Aerospace.
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- Gary Wolfe from Aurora for the core crush validation experiments and material donation.