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Damage Growth in Fluid-Ingressed Sandwich Structures

2013 Technical Review

Waruna Seneviratne & John Tomblin
Wichita State University/NIAR

Fluid Ingression & Ground-Air-Ground Effects

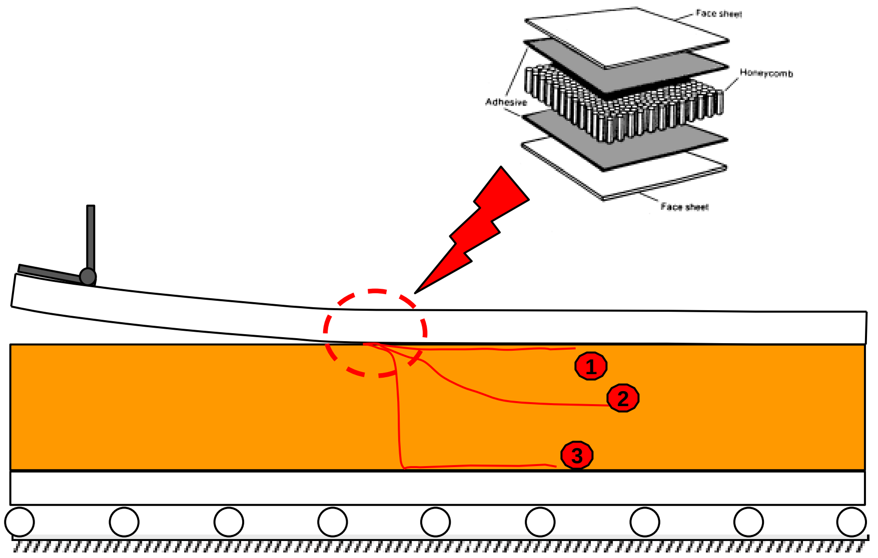
- **Motivation and Key Issues**
  - Fluid ingression phenomenon and the progressive damage growth due to entrapped fluids in sandwich structures
  - Thermo-mechanical loads during ground-air-ground (GAG) cycling result in localized mode I stresses that cause further delamination/disbond/core fracture growth creating more passageways for fluid migration.
- **Objective**
  - The influence of sandwich parameters such as core size, density, and facesheet/core stiffness ratio on the onset and damage growth rate of sandwich composite
  - Understand the Ground-air-ground effect on onset and damage growth
- **Approach**
  - Damage growth in sandwich structures
    - Core types, core densities (24, 32 and 48kg/m^3) & F/C thicknesses
  - Mechanics of different damage sources
    - Fluid ingression (GAG effects)
    - Impact damages
    - Repairs (improper repairs and process deviations)

Fluid Ingression & Ground-Air-Ground Effects

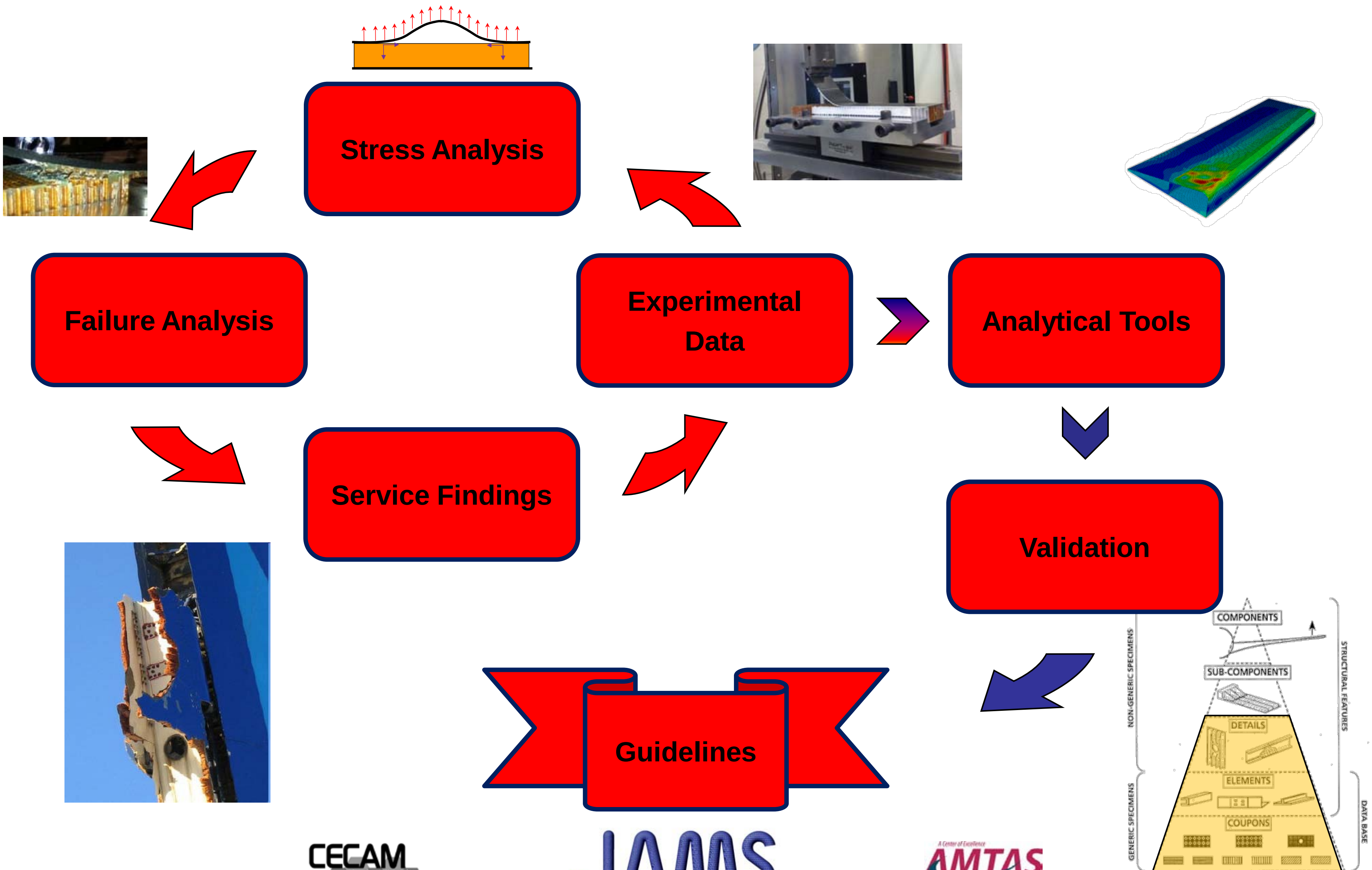
- **Principal Investigators & Researchers**
  - John Tomblin, *PhD*, and Waruna Seneviratne, *PhD*
  - *Shawn Denning*
- **FAA Technical Monitor**
  - Curtis Davies and David Westlund
- **Other FAA Personnel Involved**
  - Larry Ilcewicz, *PhD*
- **Industry Participation**
  - Cessna, Bombardier and Spirit Aerosystems

Challnges

- Standardized test methods
  - Test procedures
  - Data reduction techniques
- Complex damage mechanics
  - Onset
  - Propagation
  - Multiple constituents
- Tools for stress analysis
  - Crack-tip mode mixity
- Publically available data
  - Service findings
  - Component-level test data



Approach



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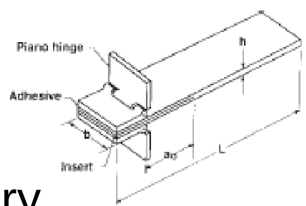
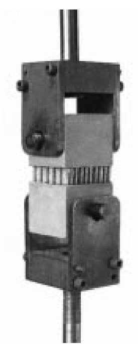
Overview Coupon Tests

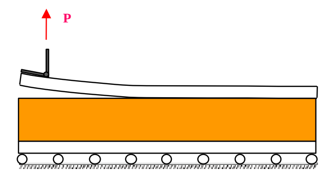
- **Double Cantilever Beam (DCB) [Modified ASTM D5528]**
  - Laminate/adhesive Mode I fracture toughness
  - Test method and data reduction
    - Static
    - Fatigue
  - Static test summary
  - R-curves
  - Fatigue curves



- **Flatwise Tension (FWT) [ASTM C297]**
  - Static test summary



- **Single Cantilever Beam (SCB) [Standards under development]**
  - Sandwich Mode I fracture toughness (DOE)
  - Test method and data reduction
    - Static
    - Fatigue
  - Static test summary
  - R-curves
  - Fatigue curves

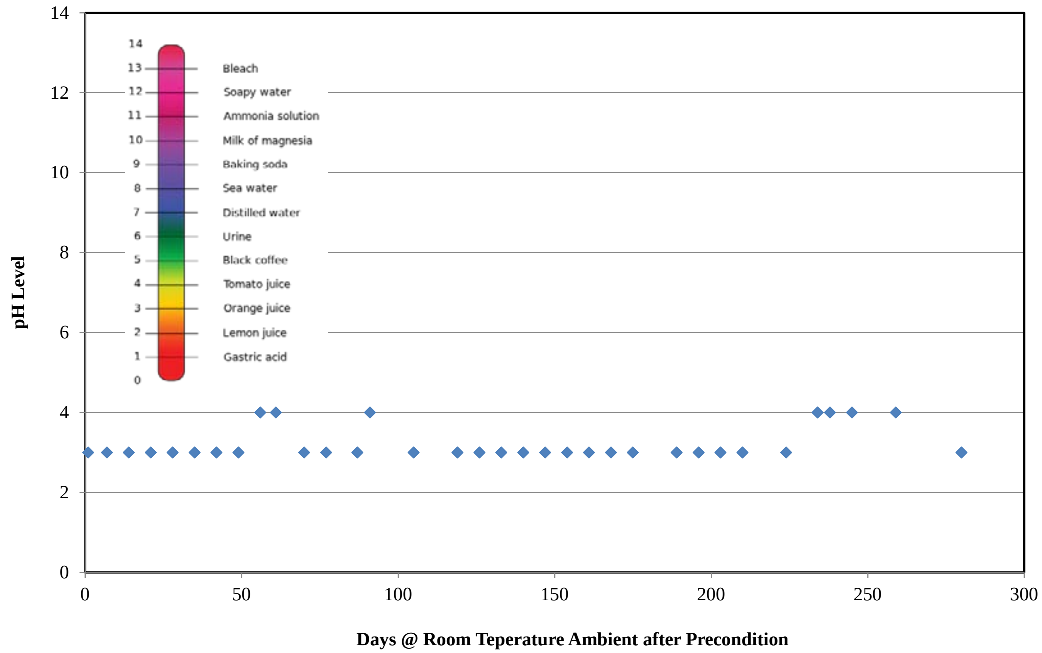


- **SKYDROL**
  - Conditioning parameters
  - Procedures

Skydrol Conditioning

- Conditioning guidelines
  - Mix ratio
  - Temperature
  - Time

Mix Ratio		Temparature		
Skydrol	Water	70^0F	120^0F	160^0F
25%	75%	x	x	x
50%	50%	x	x	x
		x	x	
75%	25%	x	x	x



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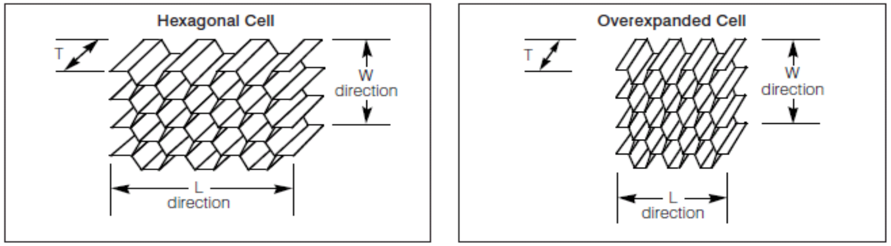
Materials

- Core
  - Hexel HexWeb HRH -10 Aramid Fiber/Phenolic Honeycomb
    - Hexagonal
    - Over-expanded

T = Thickness, or cell depth
L = Ribbon direction
W = Direction of Expansion, or direction perpendicular to the ribbon



- Facesheet material
  - Cytec AS4/E7K8 PW
  - Facesheet layups
    - 4 ply: $[0°/45°]_S$
    - 16 ply: $[0°/45°]_{4S}$

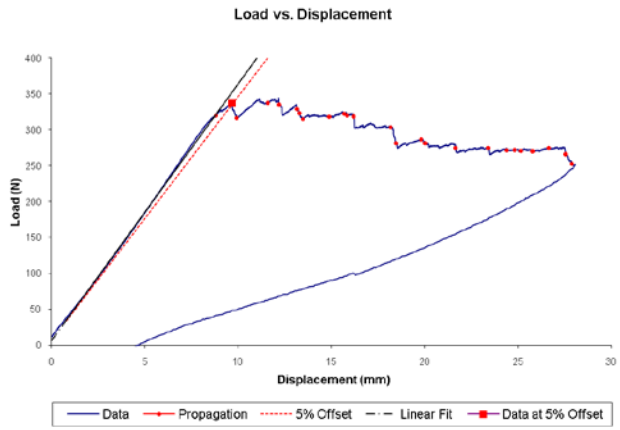
- Adhesive
  - Cytec FM 300 epoxy film adhesive

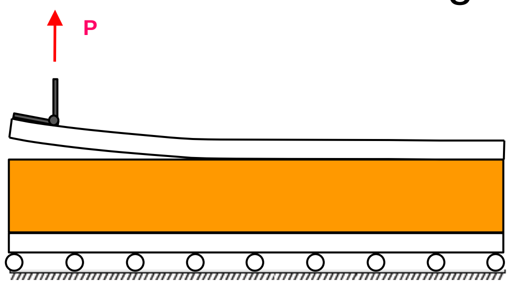
SCB Test Matrix

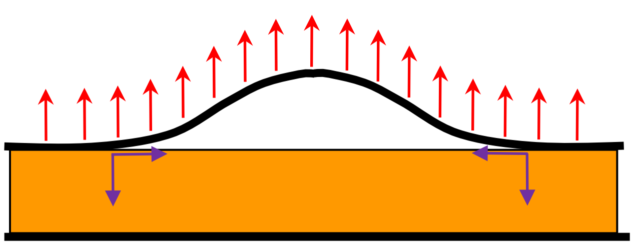
Material	Core Type	Core Thickness (in)	Facesheet (per F/C)	Cell Size (in)	Core Density	Static		Fatigue	
						Baseline	Fluid Ingressed	Baseline	Fluid Ingressed
HRH-10	Hexagonal	0.5	4-ply $[0/45]_S$	1/8	2.0				
					3.0	6	6	6	6
					6.0				
				3/16	2.0	6	6	6	6
					3.0	6	6	6	6
					6.0	6	6	6	6
				3/8	2.0				
					3.0	6	6	6	6
					6.0				
			16-ply $[0/45]_{4S}$	1/8	2.0				
					3.0	6	6	6	6
					6.0				
				3/16	2.0	6	6	6	6
					3.0	6	6	6	6
					6.0	6	6	6	6
				3/8	2.0				
					3.0	6	6	6	6
					6.0				
	OX-Core	0.5	4-ply	3/16	2.0				
					3.0	6	6	6	6
					6.0				
			16-ply	3/16	2.0				
					3.0	6	6	6	6
					6.0				
					Sub Totals	**144**		**144**	
					Total Specimens	**288**			

SCB Method

- Static testing follows Modified ASTM D 5528-01
  - 2 X 10-inch specimen
  - Initial disbond length = 2.5-inch
  - Use SCB fixture instead of DCB fixture
    - Prevents asymmetric loading
    - Prevents mixed-mode mechanics
    - Prevents kinking







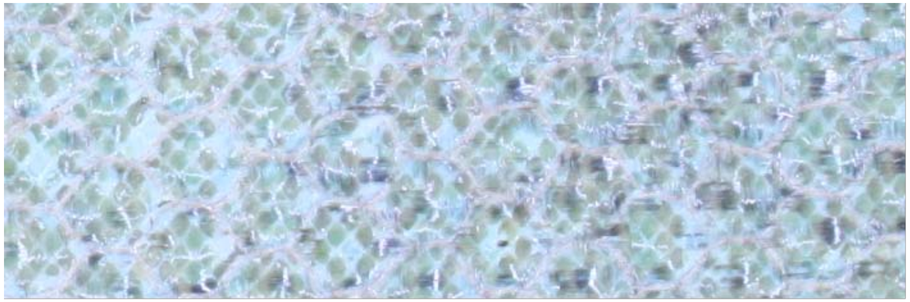
SCB Static Master Summary

Core Type	Face-sheet	Cell Size [in]	Core Density [lb/ft^3]	GIC [in-lb/in^2]											
				Baseline			Fluid Ingressed			Extended Fluid Ingressed			Water Ingressed		
				NL	VIS	5%/max	NL	VIS	5%/max	NL	VIS	5%/max	NL	VIS	5%/max
HX	4-ply [0/45]s	1/8	2.0												
			3.0	0.622	1.538	2.086	-	-	-	-	-	-	-	-	-
			3.0*	*1.149*	*3.437*	*3.644*	*1.004*	*4.710*	*4.407*	*0.422*	-	*3.725*	-	-	-
			6.0												
		3/16	2.0	0.605	1.945	2.020	-	-	-	-	-	-	-	-	-
			2.0*	*1.067*	-	*3.317*	*0.880*	*2.834*	*2.707*	*1.064*	-	*2.499*	-	-	-
			3.0	0.604	2.153	2.325	-	-	-	-	-	-	-	-	-
			3.0*	*1.362*	*3.058*	*3.740*	*0.979*	*3.590*	*3.491*	*0.994*	-	*4.393*	-	-	-
			6.0	0.596	2.012	2.349	-	-	-	-	-	-	-	-	-
			6.0*	*1.020*	*3.246*	*2.993*	*0.695*	*4.206*	*4.834*	*0.547*	-	*5.379*	-	-	-
		3/8	2.0												
			3.0	0.788	3.149	3.030	-	-	-	-	-	-	-	-	-
			3.0*	*0.868*	*2.028*	*2.533*	*0.552*	*3.685*	*4.022*	*1.044*	-	*4.578*	-	-	-
			6.0												
	16-ply [0/45]4S	1/8	2.0												
			3.0	1.912	4.603	5.475	1.201	6.226	6.393	1.950	-	6.809	3.740	-	7.633
			6.0												
		3/16	2.0	2.128	4.437	4.931	1.566	5.142	5.331	2.320	-	4.598	1.537	-	5.398
			3.0	2.305	4.961	4.842	2.501	5.713	6.151	2.475	-	8.602	3.093	-	6.050
			6.0	1.722	5.121	5.645	1.315	6.039	5.983	1.558	-	5.962	1.714	-	9.650
		3/8	2.0												
			3.0	1.567	2.813	2.877	2.052	5.263	6.816	2.298	-	5.906	2.178	-	6.366
			6.0												
OX	4-ply	3/16	2.0												
			3.0	0.583	1.712	2.195	-	-	-	-	-	-	-	-	-
			3.0*	*1.088*	-	*3.131*	*0.850*	*3.262*	*3.211*	*0.797*	-	*3.433*	-	-	-
			6.0												
	16-ply	3/16	2.0												
			3.0	1.541	5.483	6.017	1.206	4.973	5.074	1.149	-	5.022	1.849	-	4.743
			6.0												

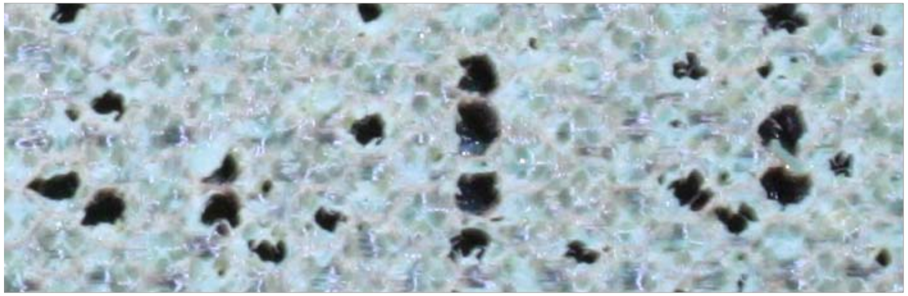
NOTE: * - ao = 1 inch

Primary Failure Modes

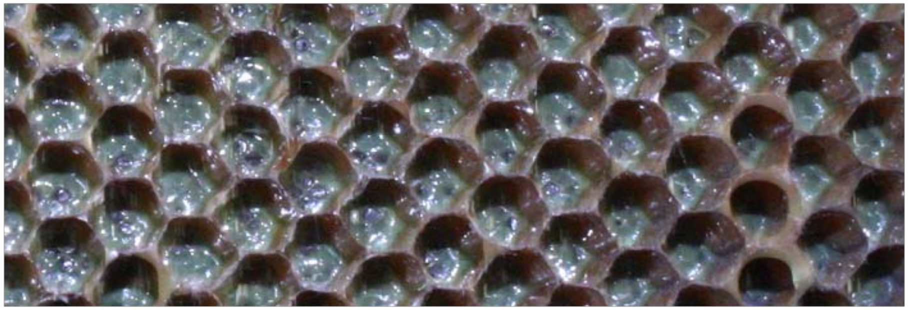
- Adhesive Interface Disbond (A)



- Adhesive Pullout (PO)



- Tensile Core Failure (S)



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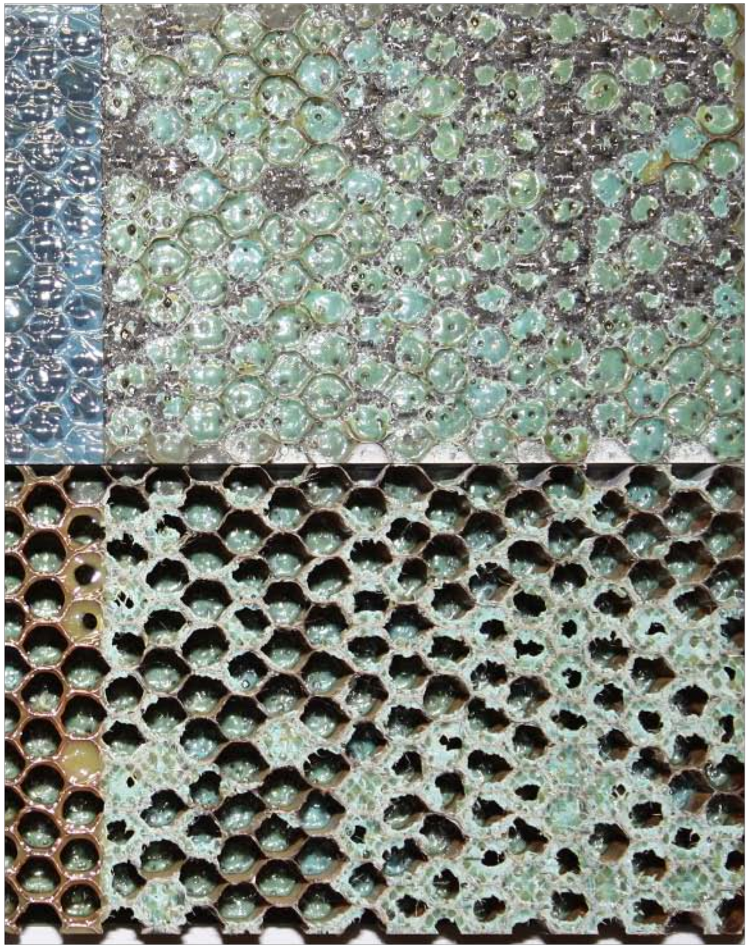
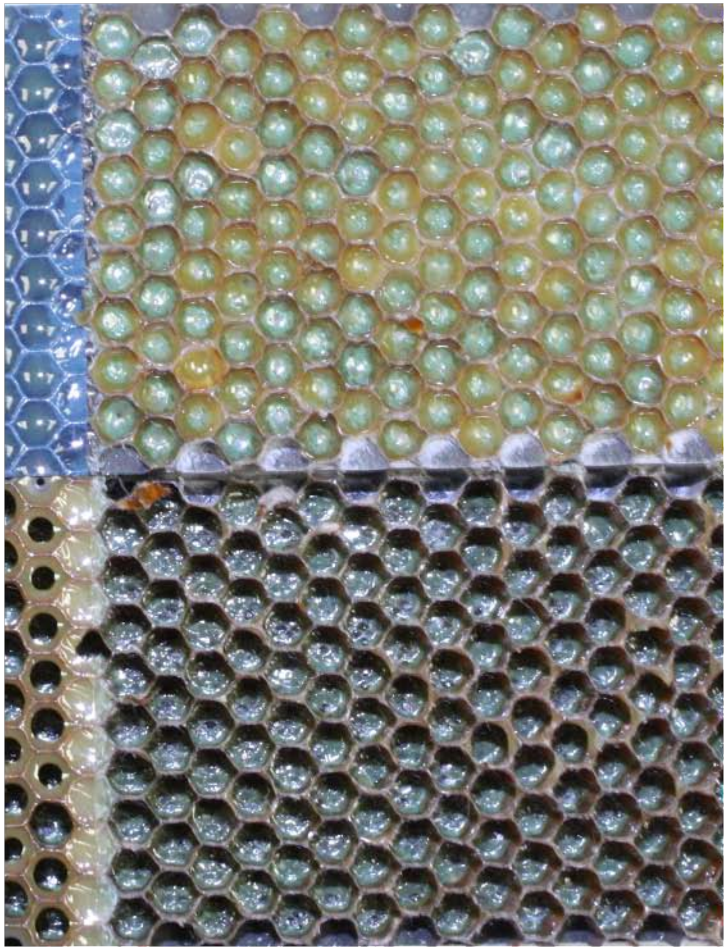
Failure Surface - HEX





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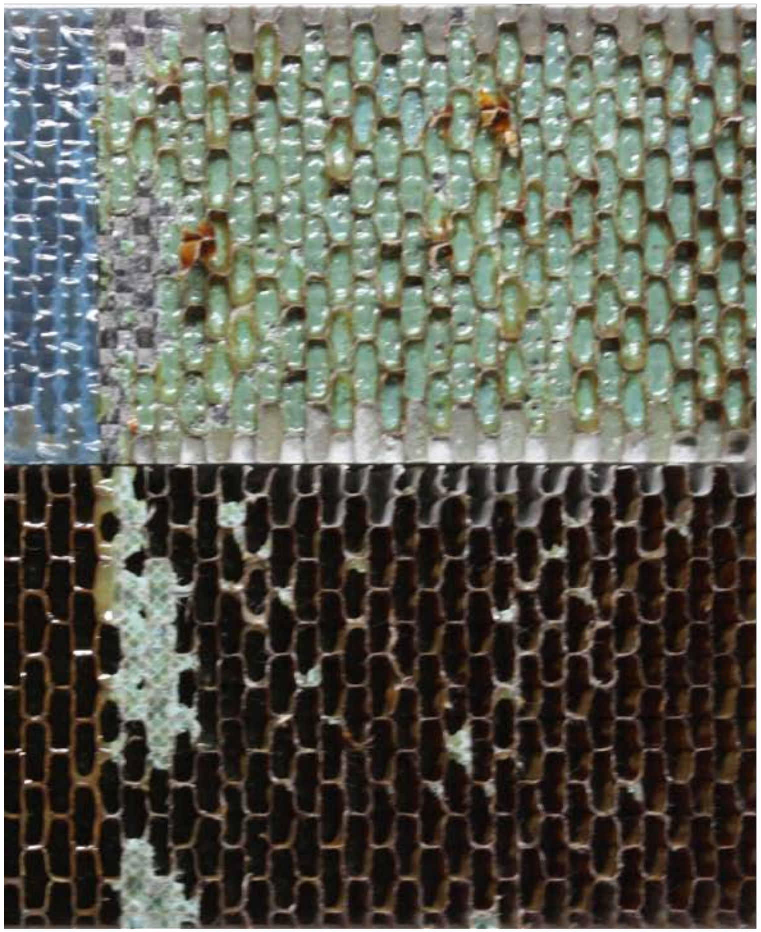
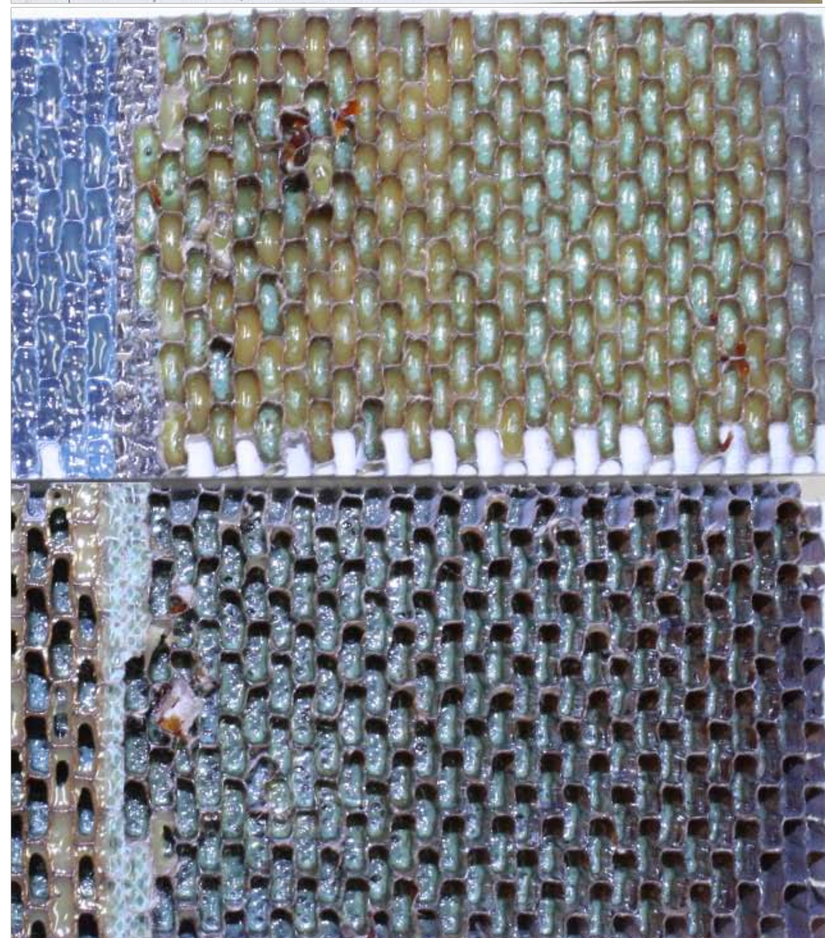
Failure Surface - OX





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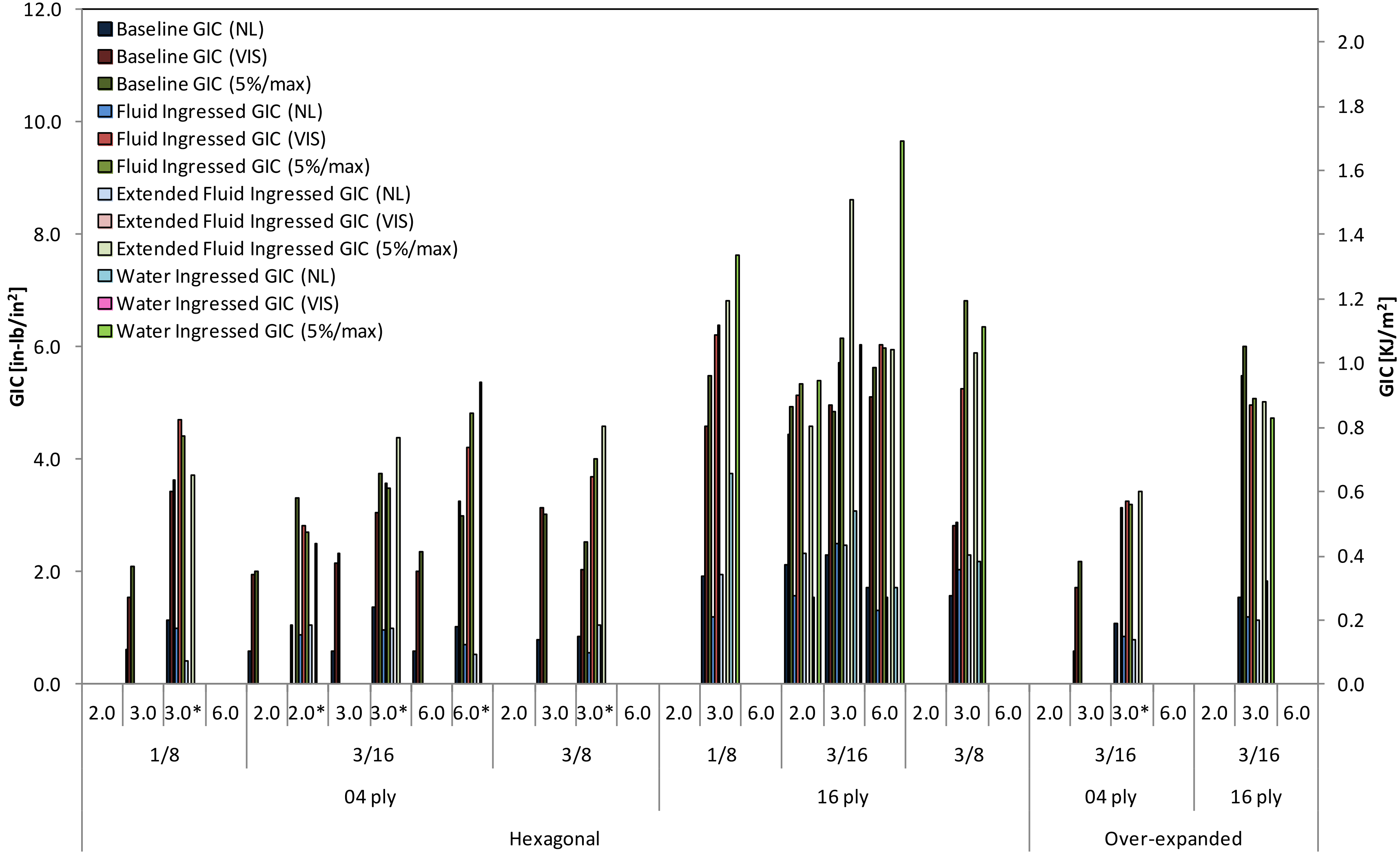
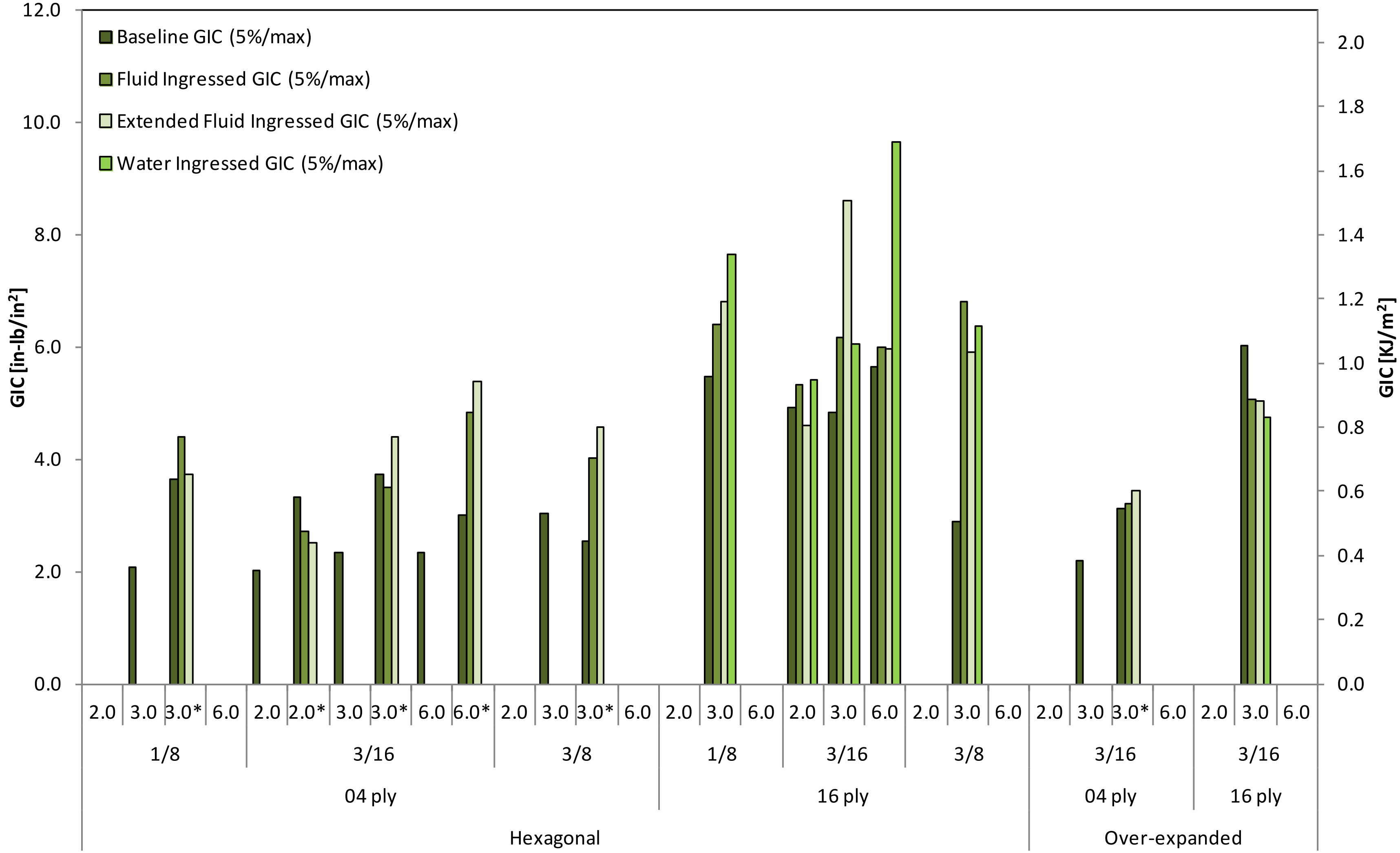
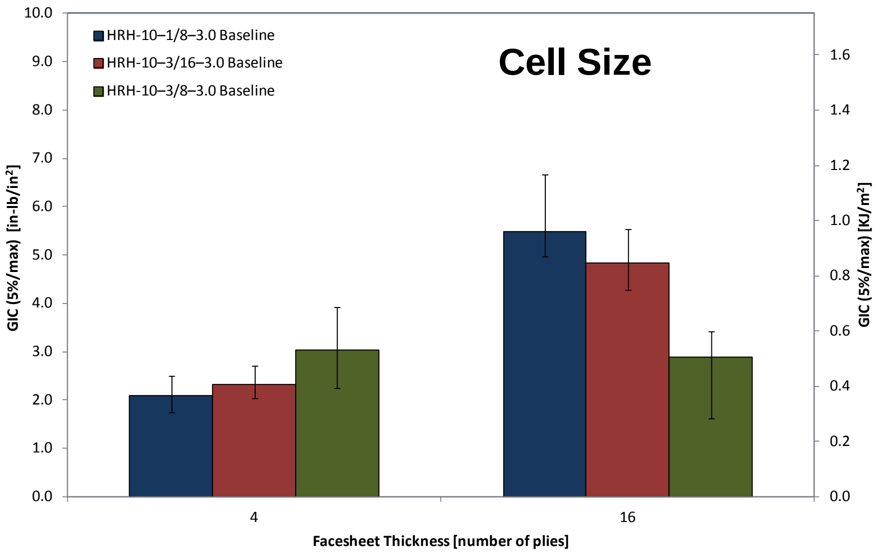
SCB Static Summary

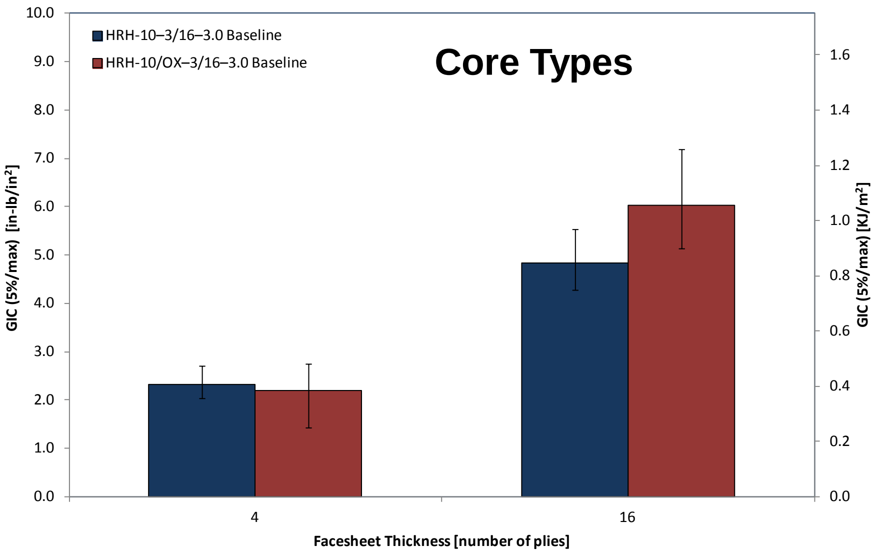


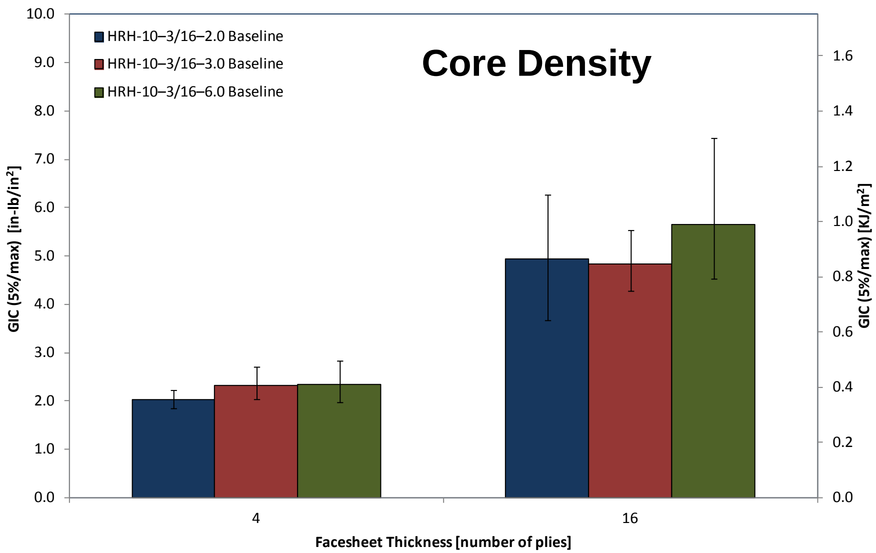
SCB Static Summary (5% Max)

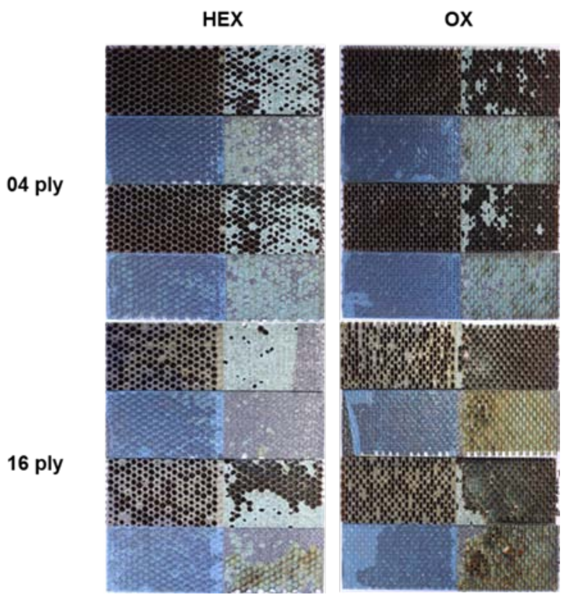


Effects of Facesheet Thickness









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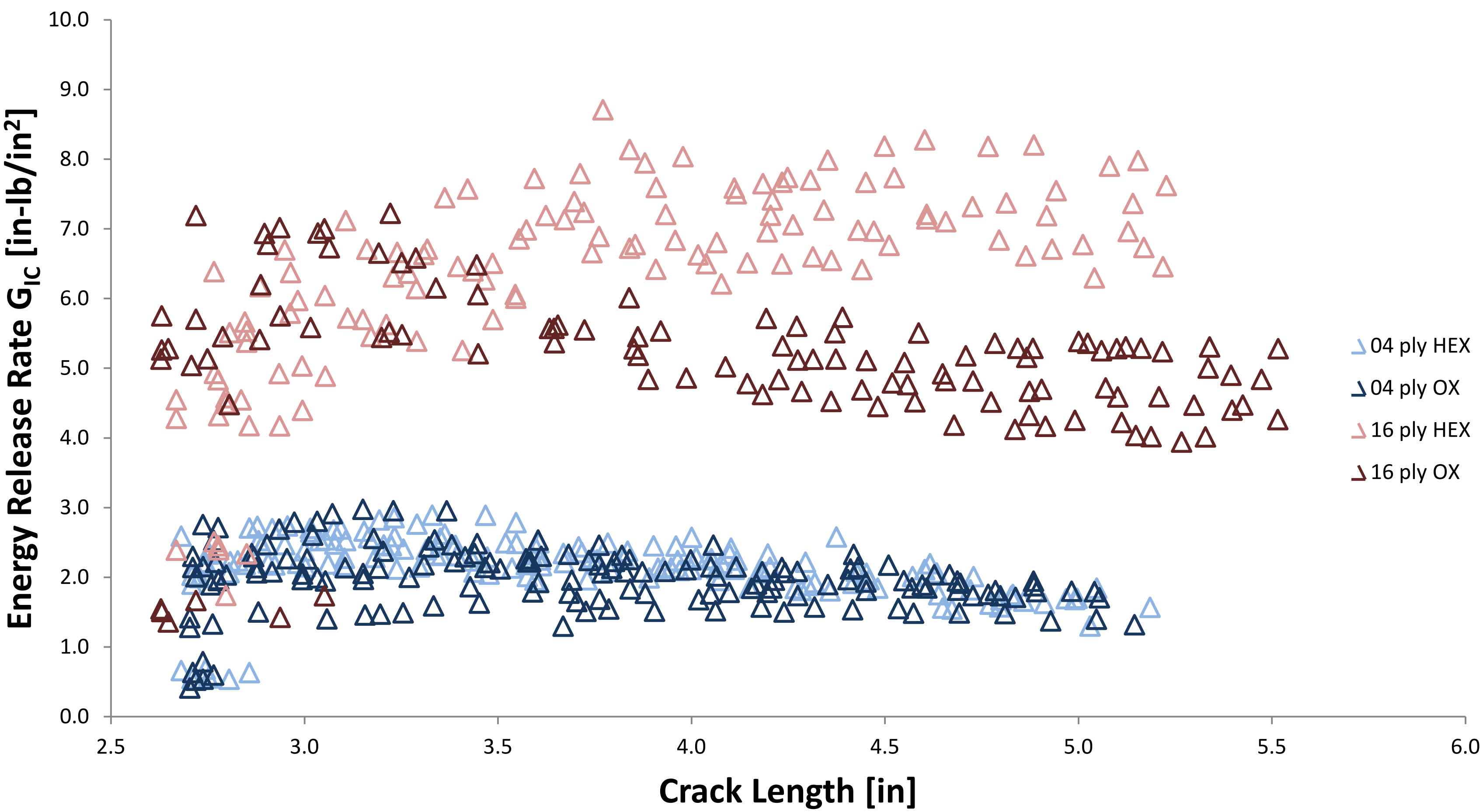
Propagation Curve of various Cell Types with respect to Facesheet Thickness



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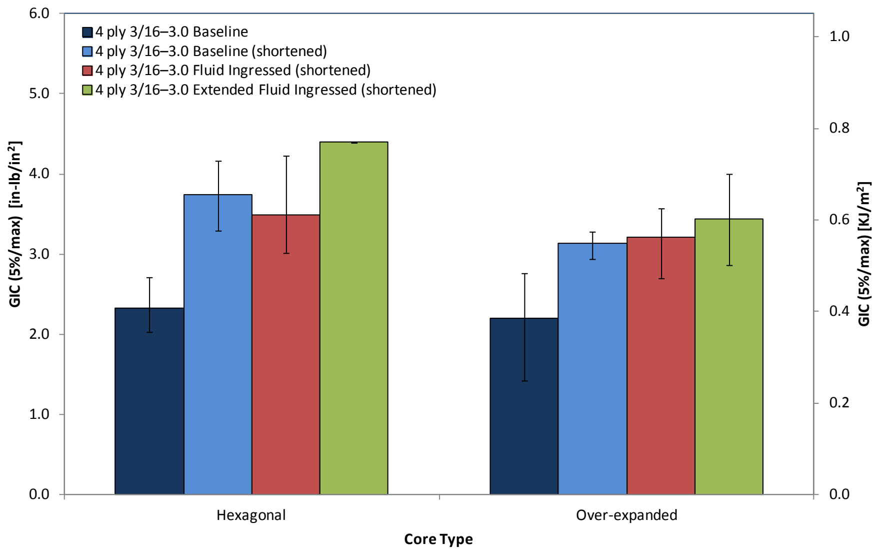
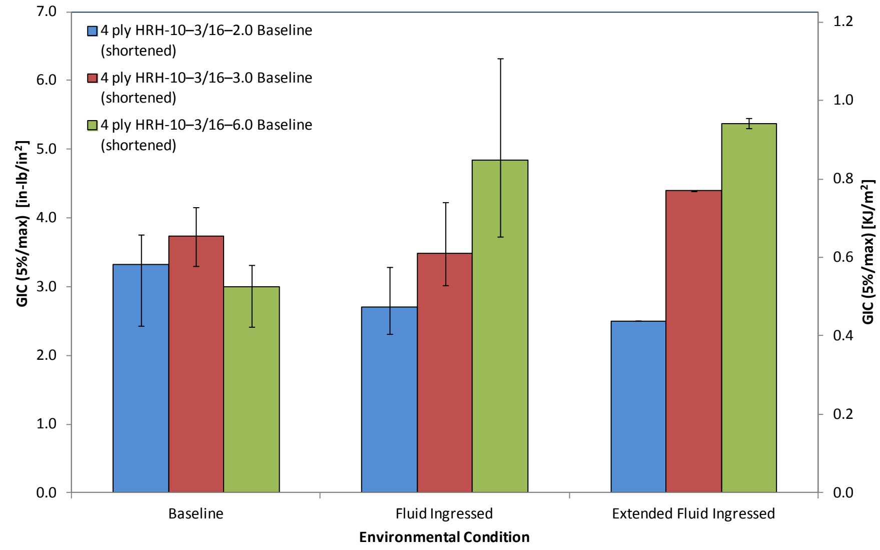
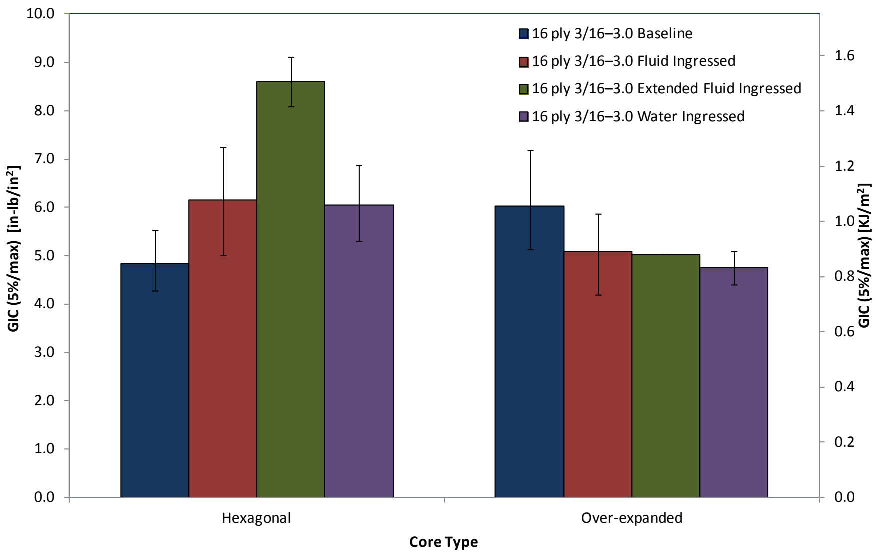
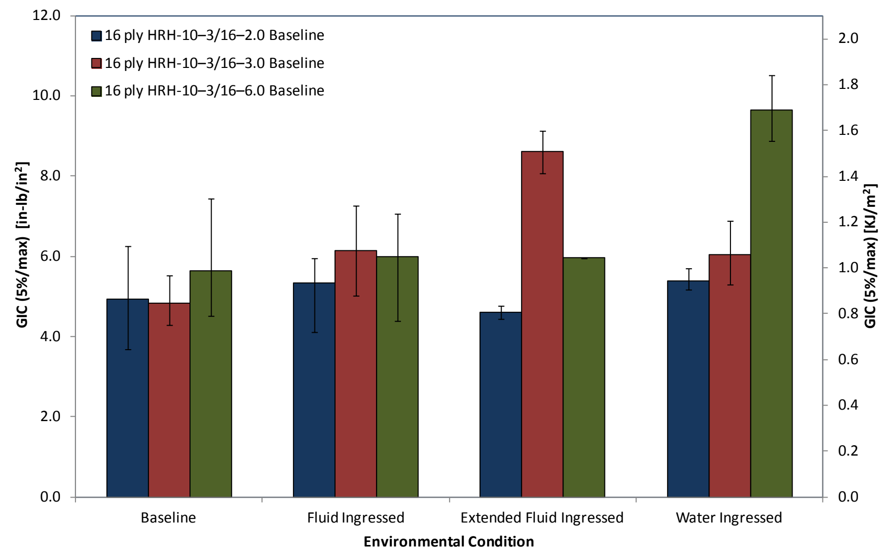
Effects of Environment









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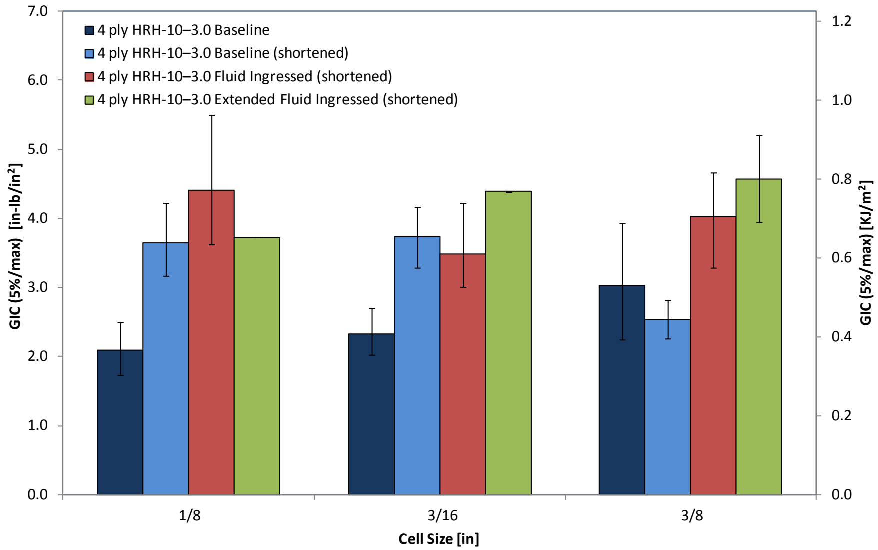
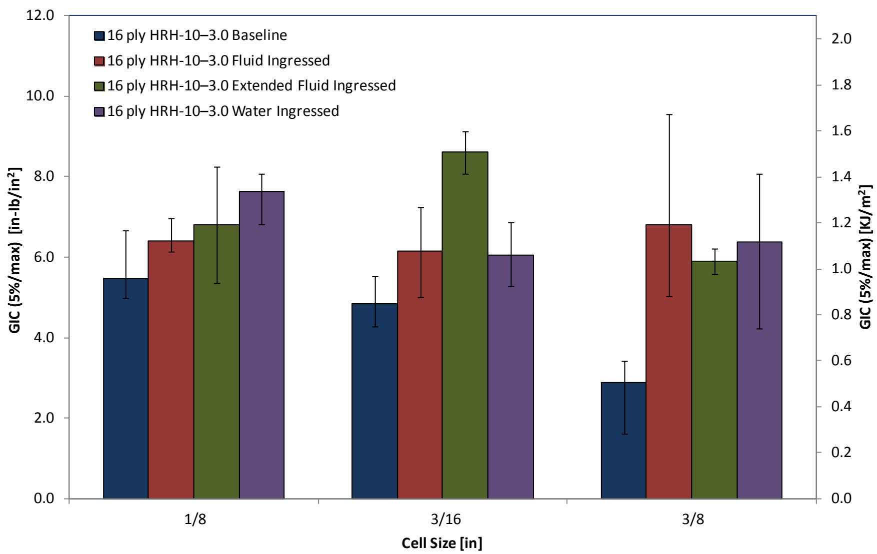
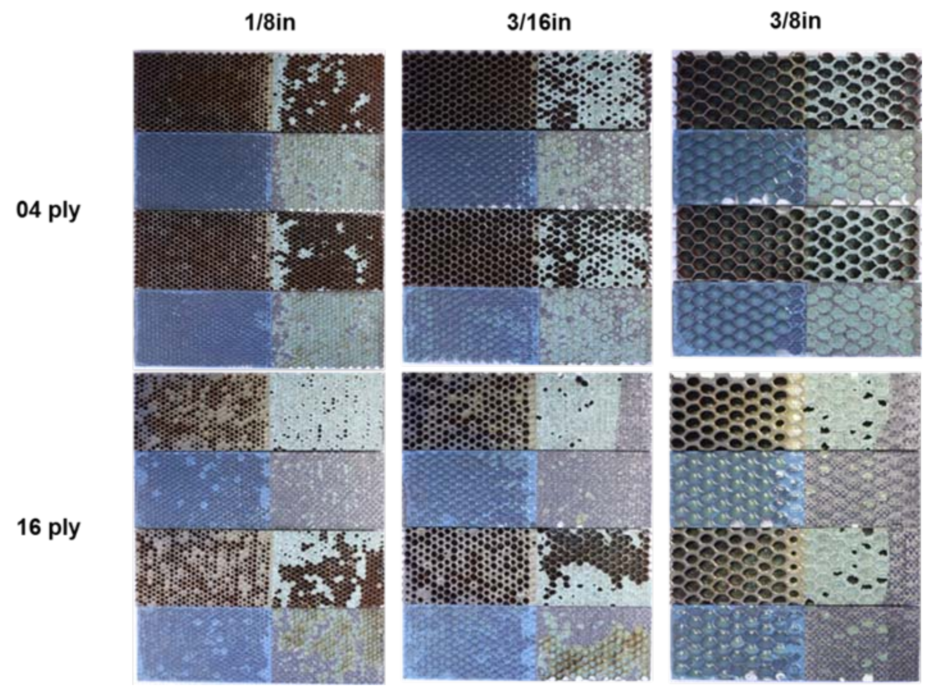
Effects of Cell Size







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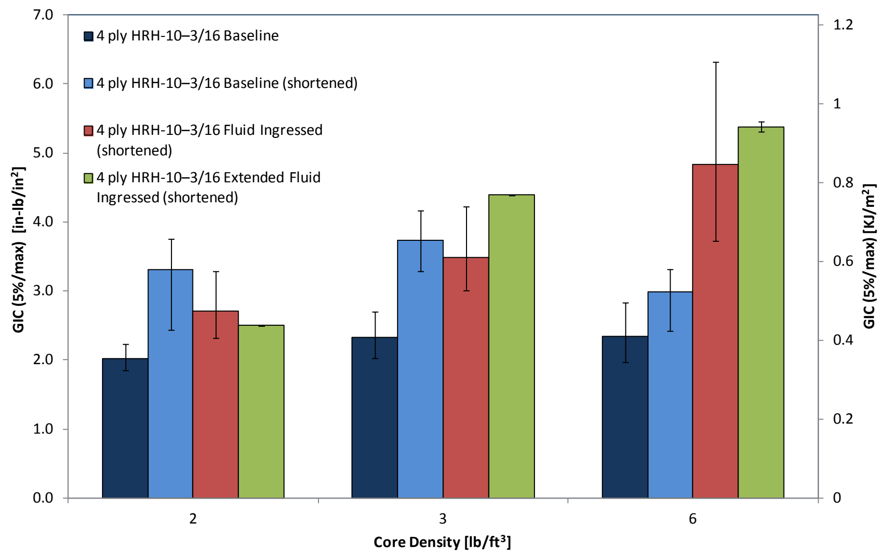
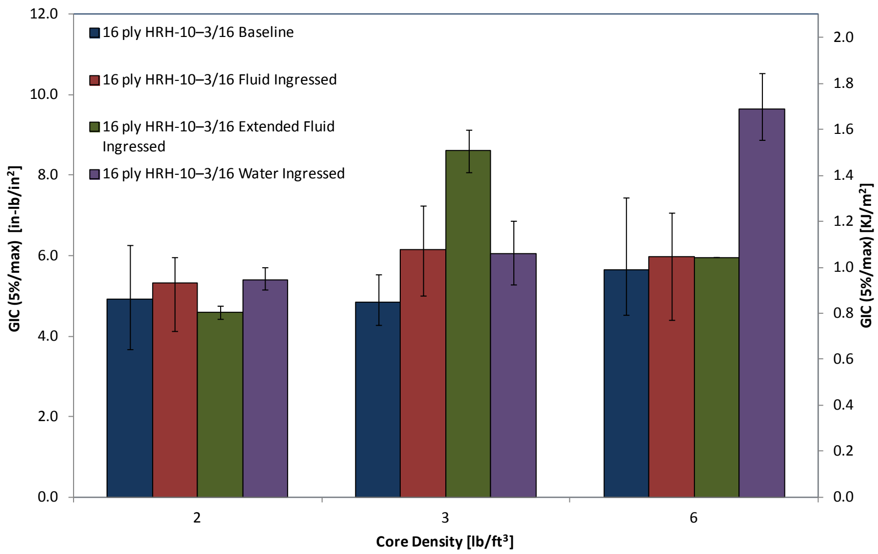
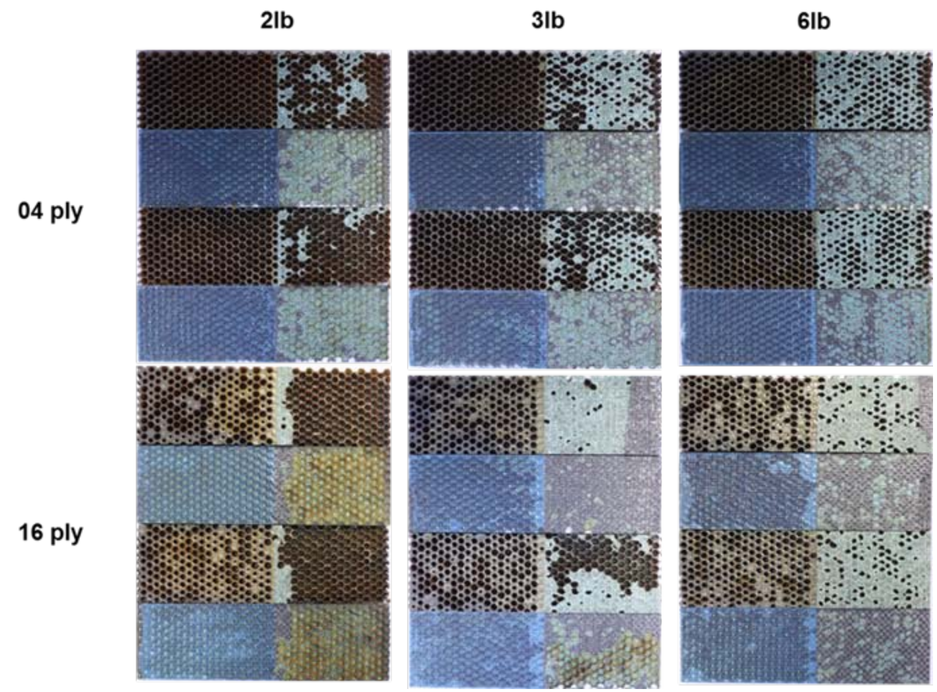
Effects of Core Density







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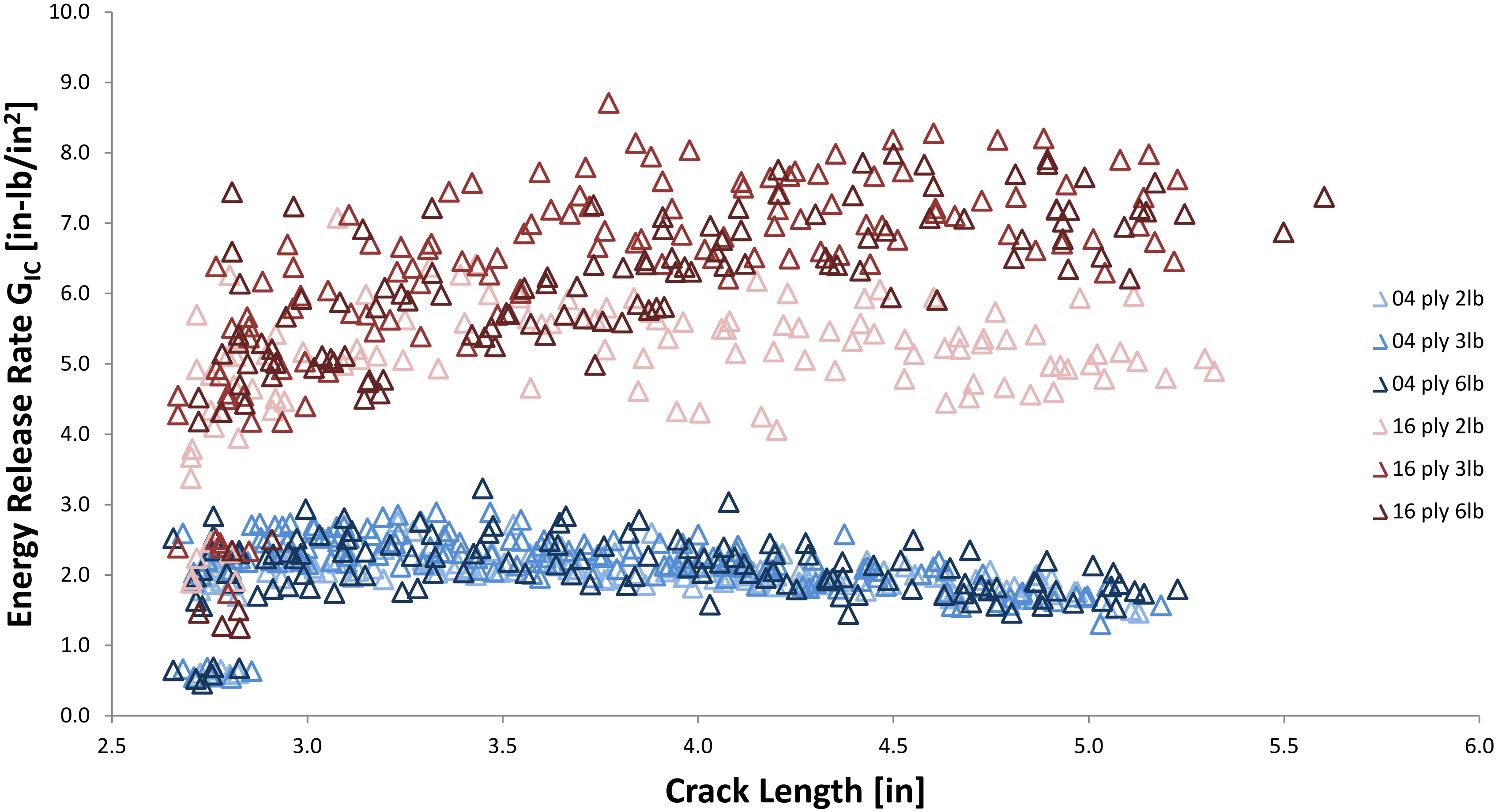
Propagation Curve of various Cell Densities with respect to Facesheet Thickness



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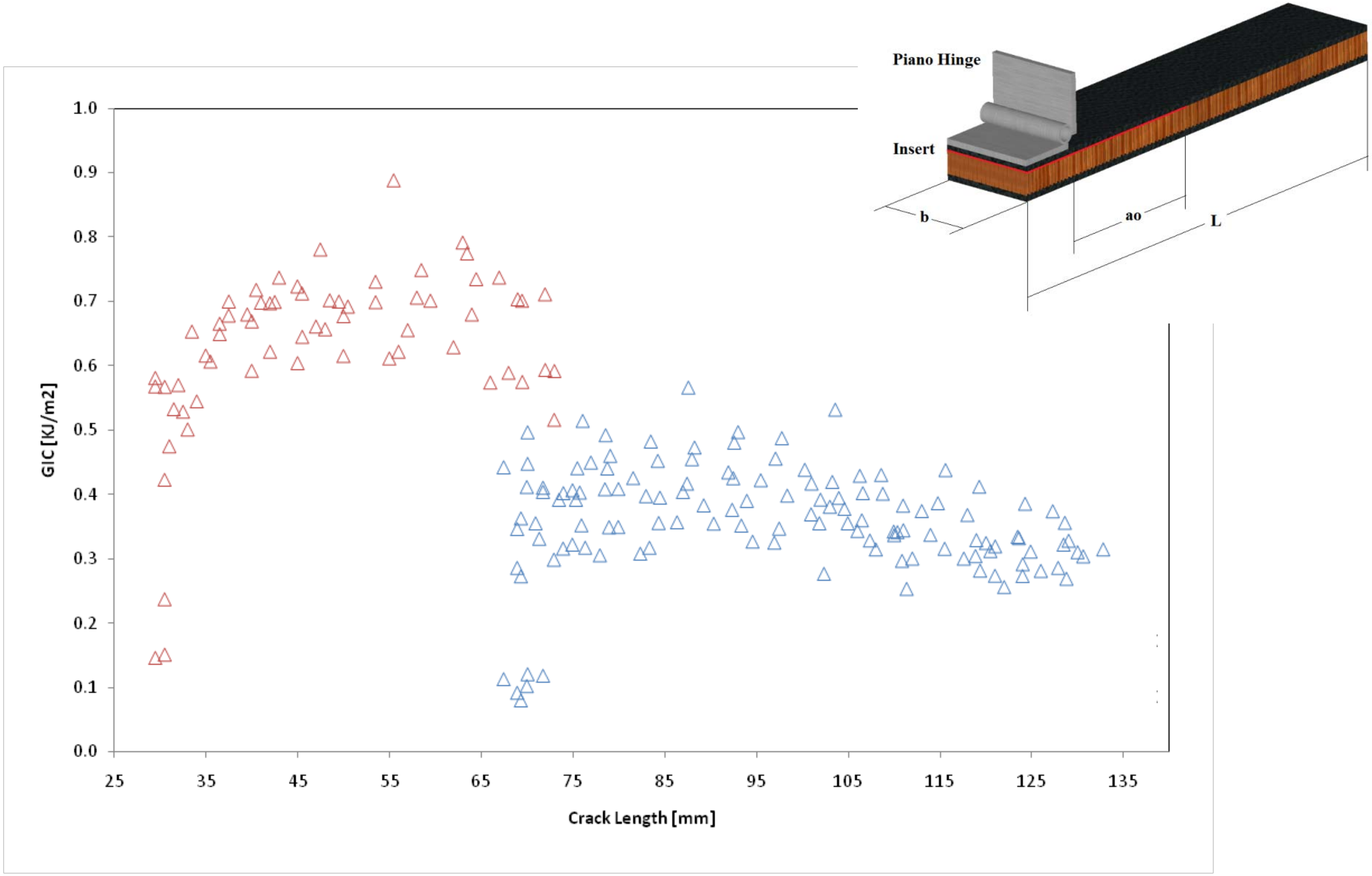
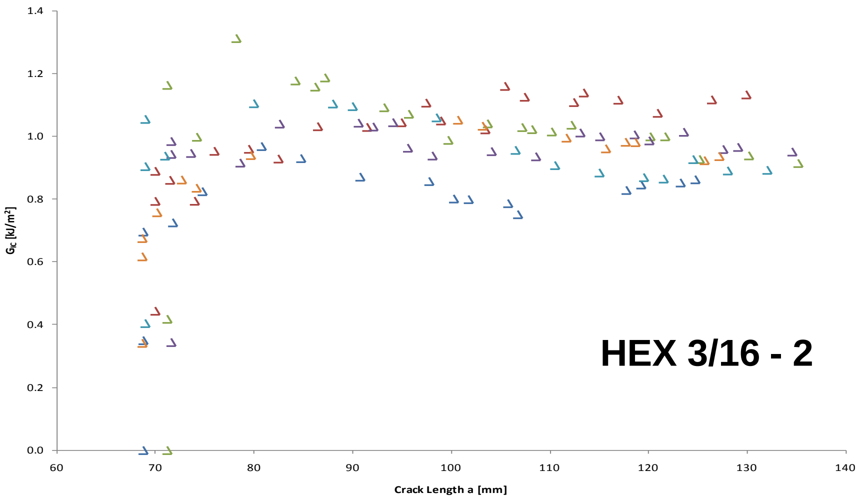
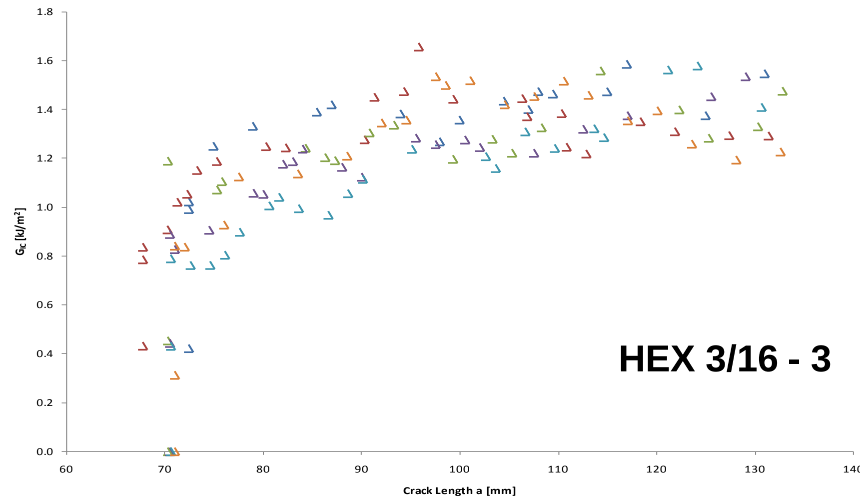
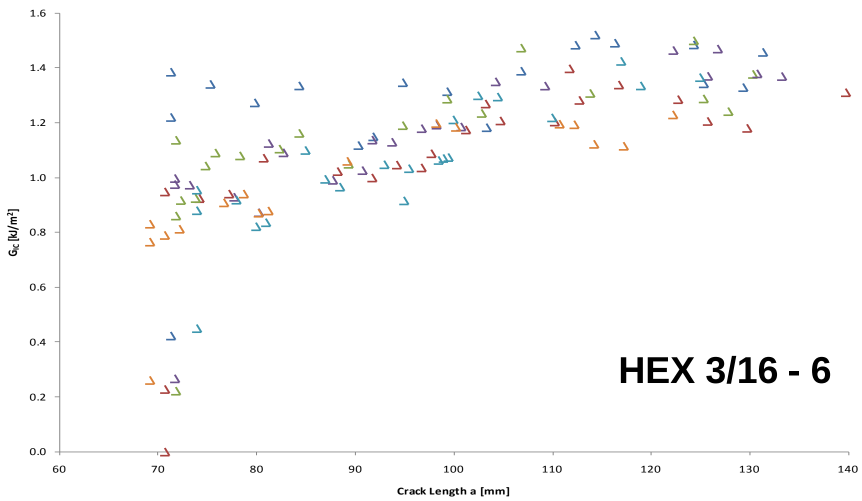
Effects of Precrack Length

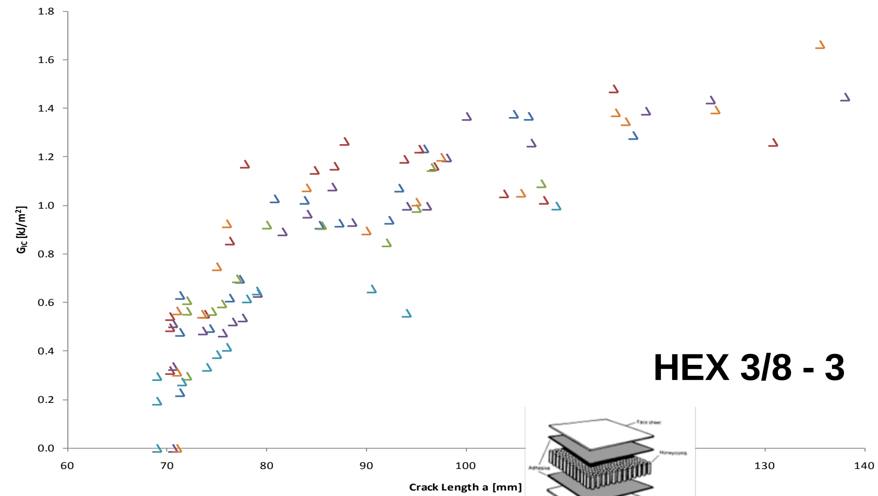


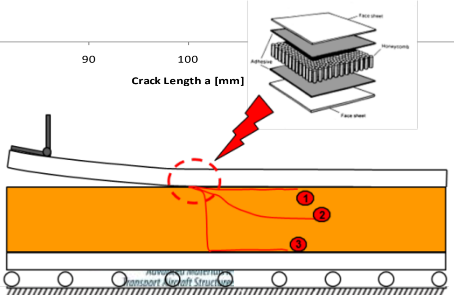
SCB Static Test Data Scatter



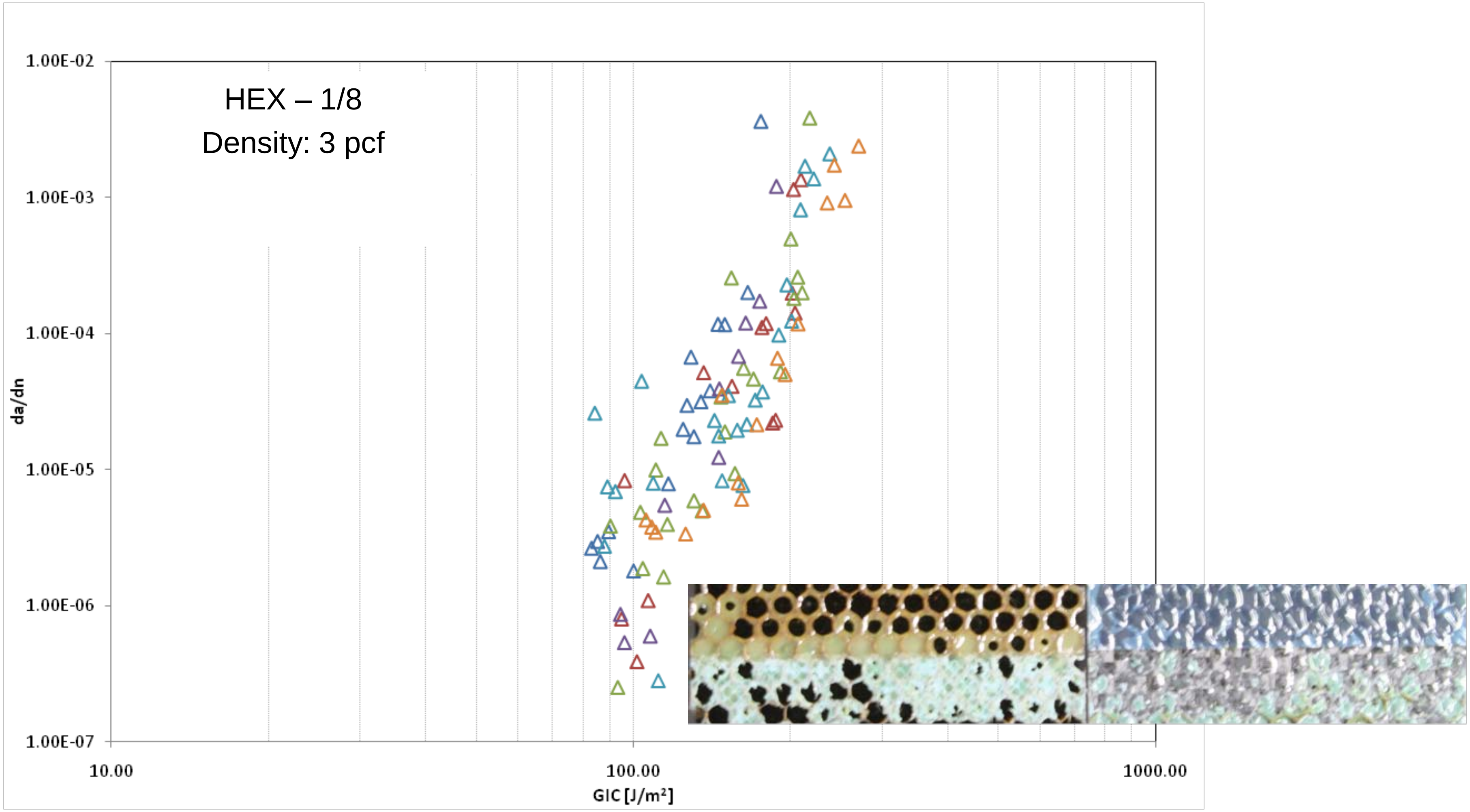








SCB Fatigue Crack Growth Data



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Summary

- Based on the preliminary DCB and SCB tests conducted on sandwich fracture toughness specimens, it was found that SCB specimens are most suitable for determining the Mode I fracture toughness of sandwich specimens.
- The failure modes are complex and often a mixture of the primary crack propagation modes identified in this presentation.
- This study was further extended to evaluate the damage growth rate under cyclic loading for similar parameters discussed in this presentation.
- Several other key parameters such as effects of ribbon direction, fabrication procedures, crack starter location, etc. are studied as a supplemental test matrix.
- FAA final reports
  - Damage Growth in Sandwich Structures (Vol. I)
  - Fatigue Damage Growth Rate in Sandwich Structures (Vol. II)

Looking Forward

- **Benefit to Aviation**
  - Guidelines for substantiating sandwich structures
    - Fluid ingression phenomenon
    - GAG effects on damage growth
    - Effects of geometry and sandwich parameters on fracture toughness and damage growth rates
- **Future needs**
  - Field history data related to sandwich data growth phenomenon
  - Analytical methods
  - Standardized test procedures

End of Presentation.

Thank you.

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