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Environmental Compensation Factor Influence on Composite Design and Certification

2012 Technical Review

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Environmental Compensation Factor Influence on Composite Design and Certification

- **Motivation and Key Issues**
  - Moisture absorption characteristics of composites, which follow Fick's second law, can be coupled with realistic environmental data to design structurally efficient and economic composite components. This research will provide guidance to establish practical levels of moisture content and corresponding environmental compensation factors for composite structures.
- **Objective**
  - Develop guidelines for the development of environmental enhancement factors for static strength loading

Approach

- Develop guidelines for the development of environmental enhancement factors for static strength loading
- Use data developed at lamina, laminate, element and subcomponent to demonstrate application
- Incorporate a probabilistic model, which accounts for the environmental factors affecting composite design
- Address any additional research & development needs with environmental factors as budget allows, i.e. effects of non-Fickian processes such as capillary action along fiber/matrix interface and through cracks and voids, effects of surface cracking in the resin at free edges due to swelling stresses resulting from moisture desorption on subsequent moisture absorption, environmental factors for adhesive joints and sandwich construction, etc.

Environmental Compensation Factor Influence on Composite Design and Certification

- Principal Investigators & Researchers
  - John Tomblin, *PhD*, and Waruna Seneviratne, *PhD*
  - Upul Palliyaguru, Shawn Denning, Janith Senaratne
- FAA Technical Monitor
  - Curtis Davies, Daivd Westlund
- Other FAA Personnel Involved
  - Larry Ilcewicz, *PhD,* and Peter Shyprykevich *(ret.)*
- Industry Participation
  - Cessna, Bombardier, Hawker Beechcraft, and Spirit Aerosystems

Environmental load factor

- to satisfy FAA certification requirements for composite structures, FARs require compliance with 23.573, 23.603, 23.613 and 23.619 (can apply also to Part 25 aircraft). General guidelines for a composite structure should be considered which are over what is normally done for metallic certifications (i.e., account for the *difference* between composite and metallic structures in certification)

- an approach which may be used, when combined with analytical modeling, is to apply these “overloads” within the model to demonstrate compliance after a successful static structural test (may also be applied during the test) and demonstrating positive margins of safety throughout the structure

Static Load Factor

***SLF = Static Load Factor* »** **represents the difference in load factor between a composite and metallic structure**

Will depend on material system, layup (lamina or laminate), failure mode, damage ….. Based upon some existing data, this could be as high as 1.32

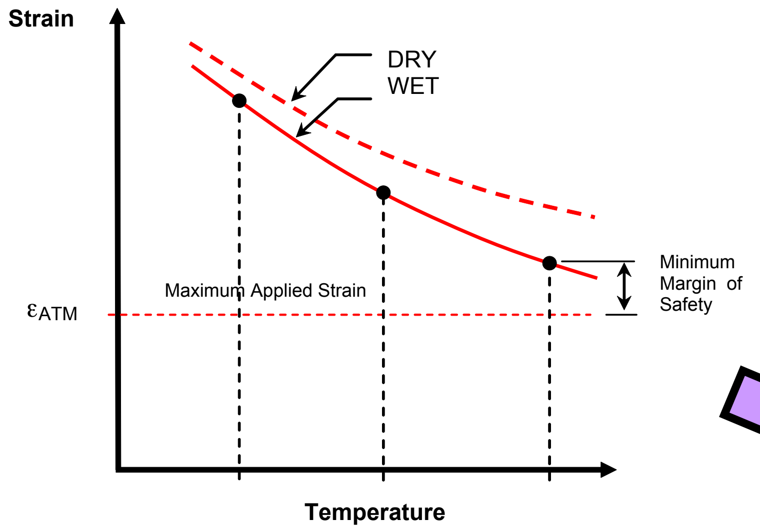
$$SLF = \frac{C_{\substack{composite \\ variability}} \; C_{\substack{composite \\ temperature}} \; C_{\substack{composite \\ moisture}}}{F_{\substack{metals \\ variablity}} \; F_{\substack{metals \\ temperature}} \; F_{\substack{metals \\ moisture}}}$$

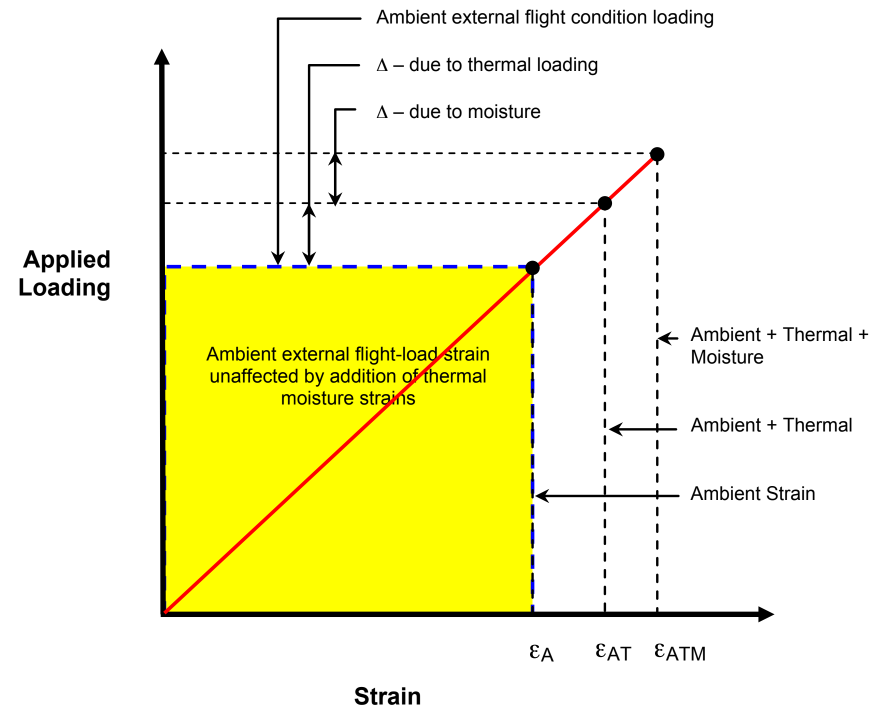
Room for improvement in this based upon failure mode in temperature (based upon FEM M.S. model) and amount of moisture actually expected in structure during lifetime

1

Based on percentage of strength at 180 °F, approximately 1.04

Design & Certification





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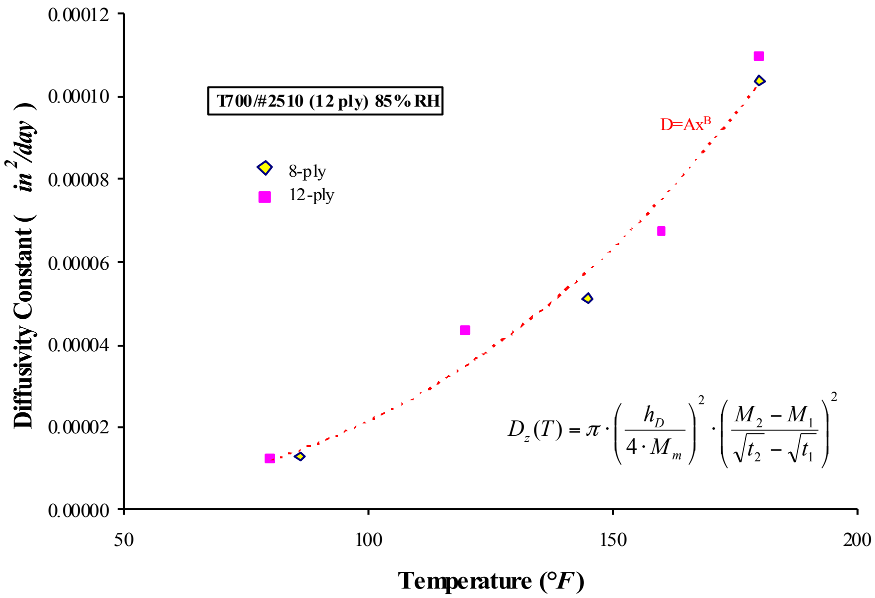
Analysis Assumptions

- Fickian Diffusion
  - Assumptions
    - Moisture concentration behaves according to:

$$\frac{\partial c}{\partial t} = D_z \frac{\partial^2 c}{\partial z^2}$$



- Diffusion behavior constant through thickness
  - Cloth vs. Uni differences are negligible
- Steady state only
- Two sided diffusion
- Through the thickness diffusion dominates
  - End effects neglected

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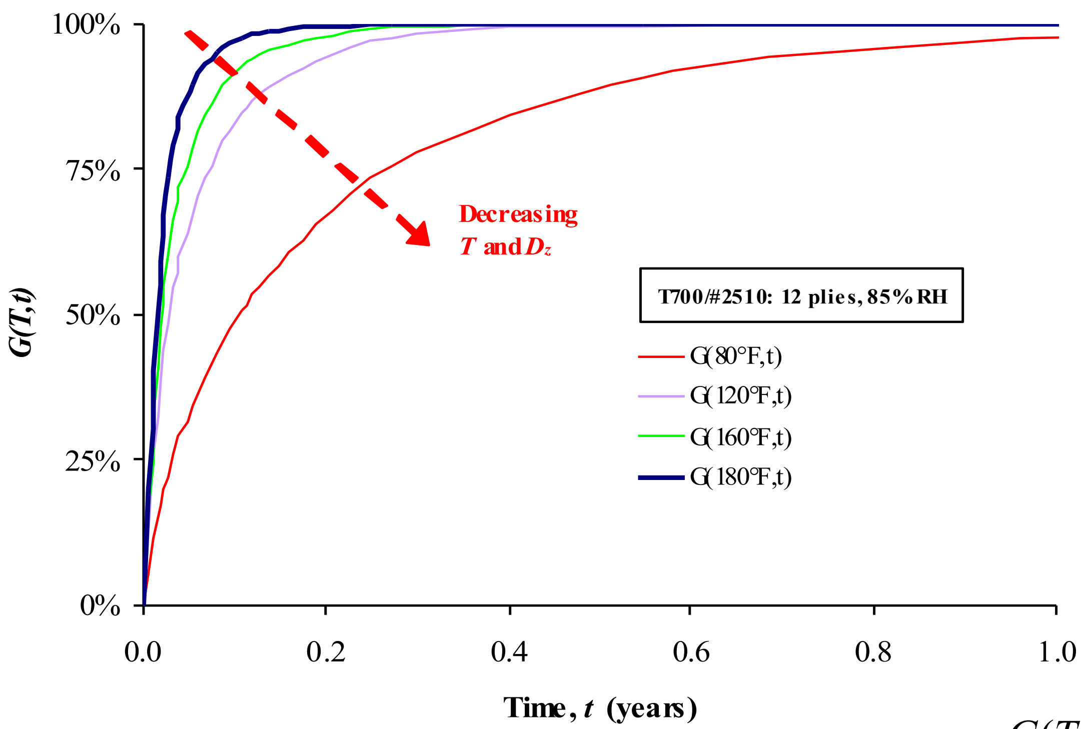
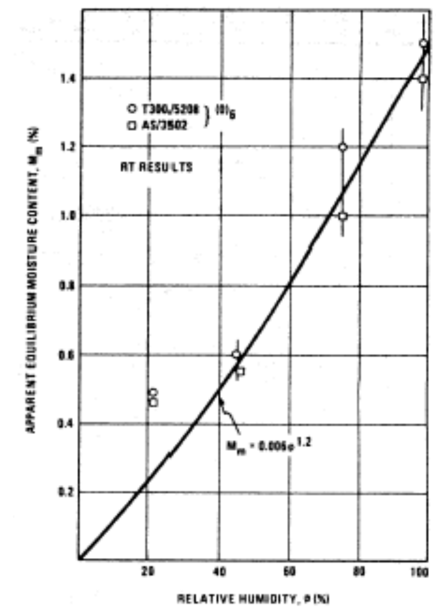
Saturation Levels

- *G(T,t)* is the ratio of moisture level at a given time to the saturated moisture content *(M_m)*





$$G(T,t) = 1 - \exp\left[-7.3 \cdot \left(\frac{D_z(T) \cdot t}{h^2} \right)^{3/4} \right]$$

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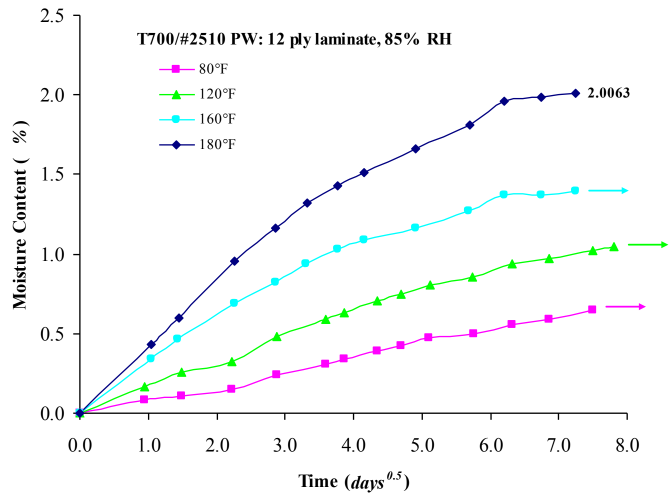
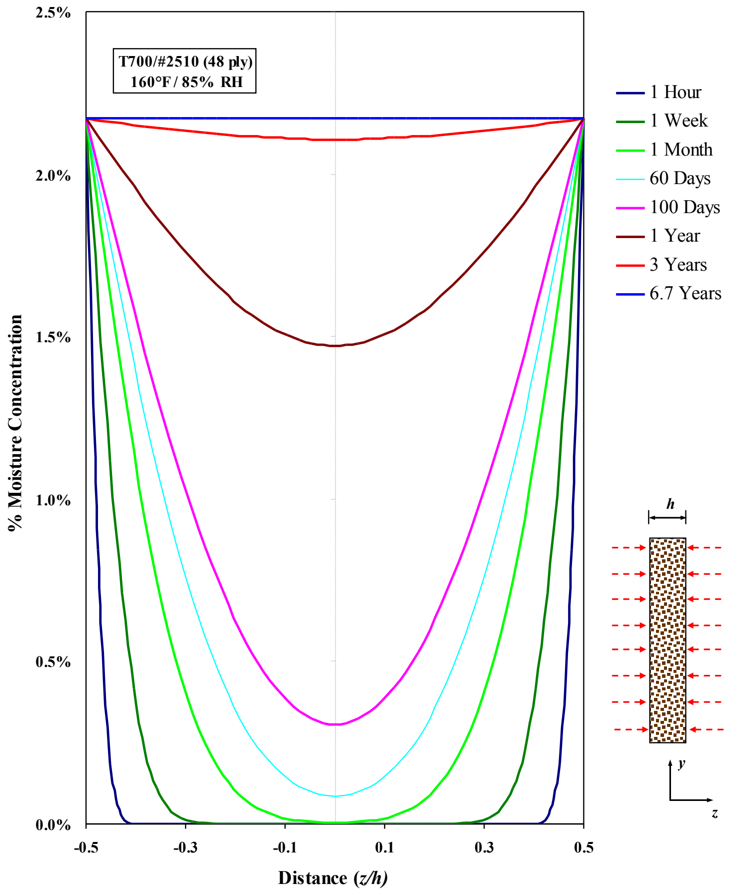
Moisture Absorption





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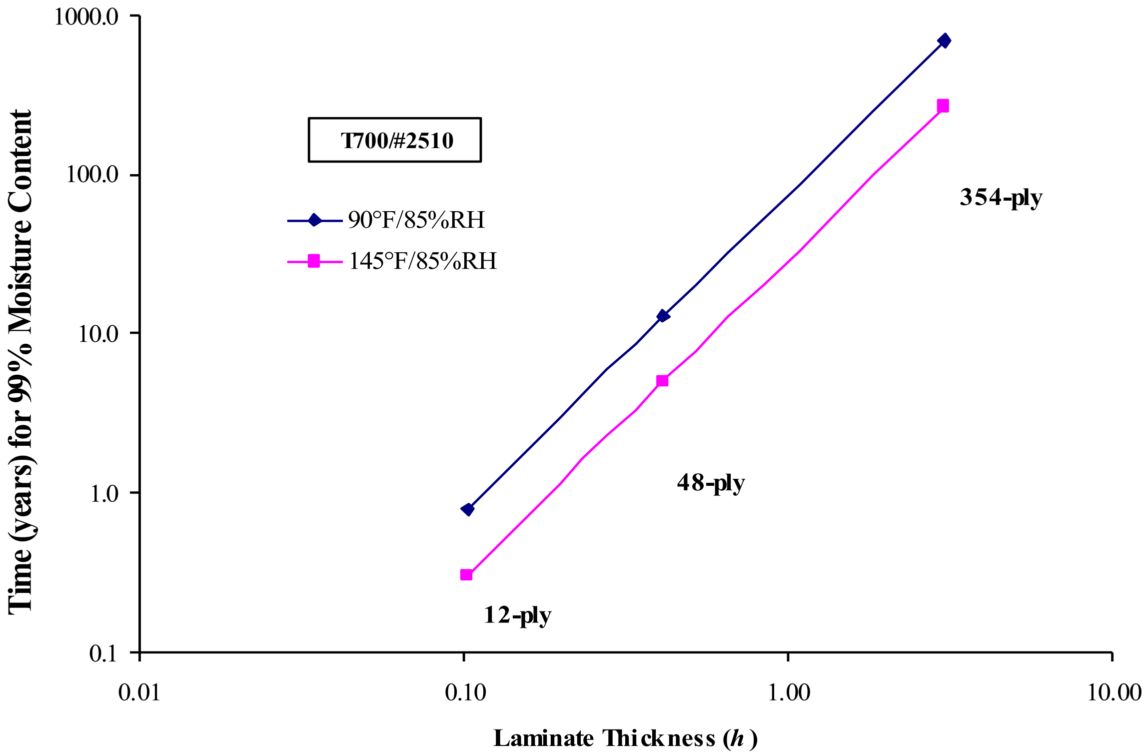
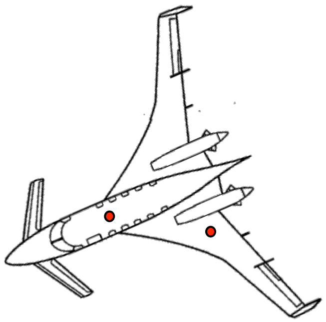
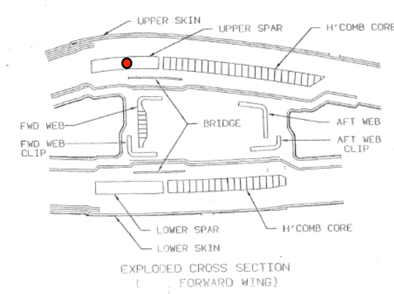
Moisture Absorption for Full Scale Articles

- What is realistic?

Laminate Thickness (in)	Years for 99% Saturation		
	0.1032	**0.4128**	**3.0444**
90°F/85%RH	0.8	12.8	696.6
145°F/85%RH	0.3	5.0	269.4

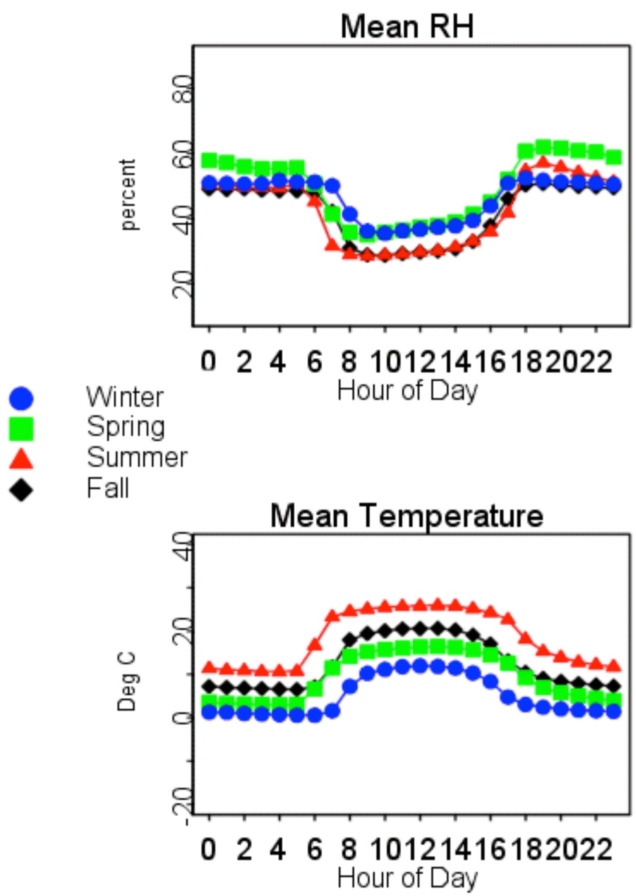




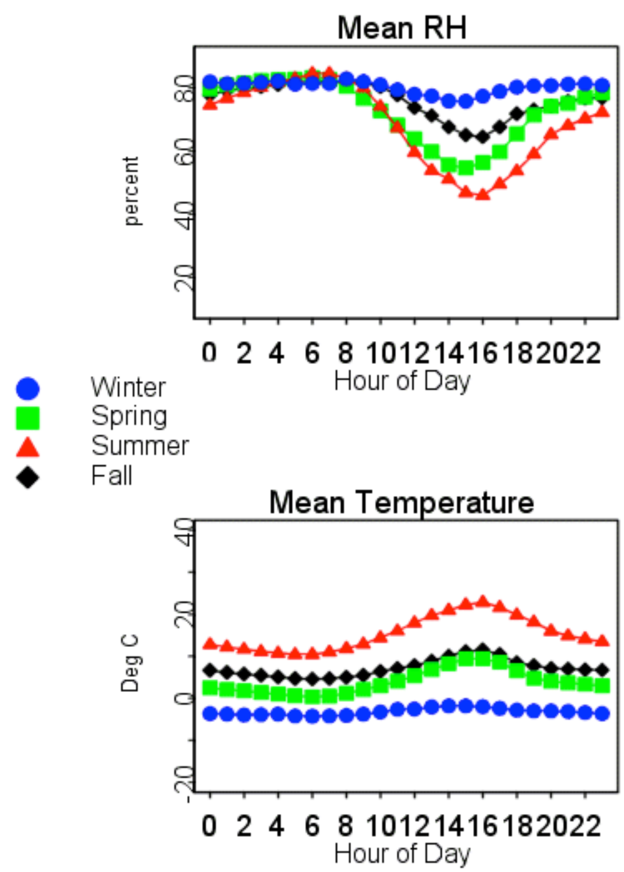


Environmental Data

San Gorgonio
64,164 Obs., 1 Mar 1989 - 31 May 1999



Glacier Natl. Park
35,495 Obs., 20 Jan 1989 - 31 May 1999



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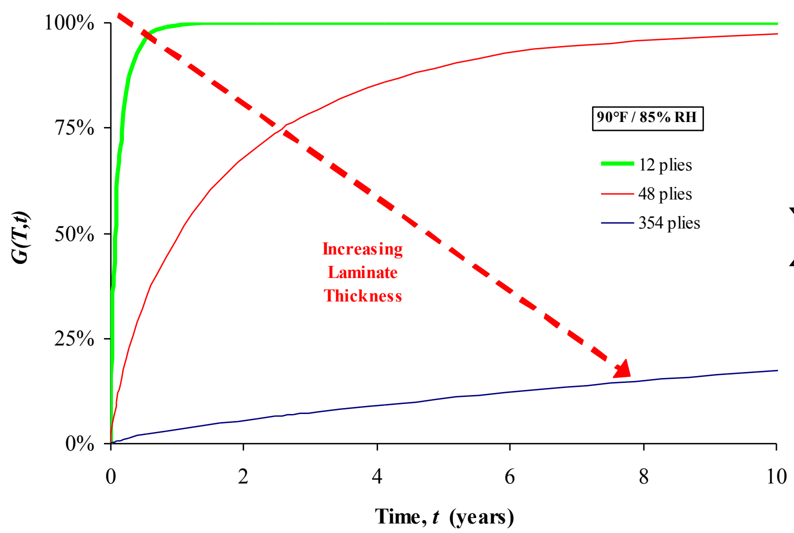
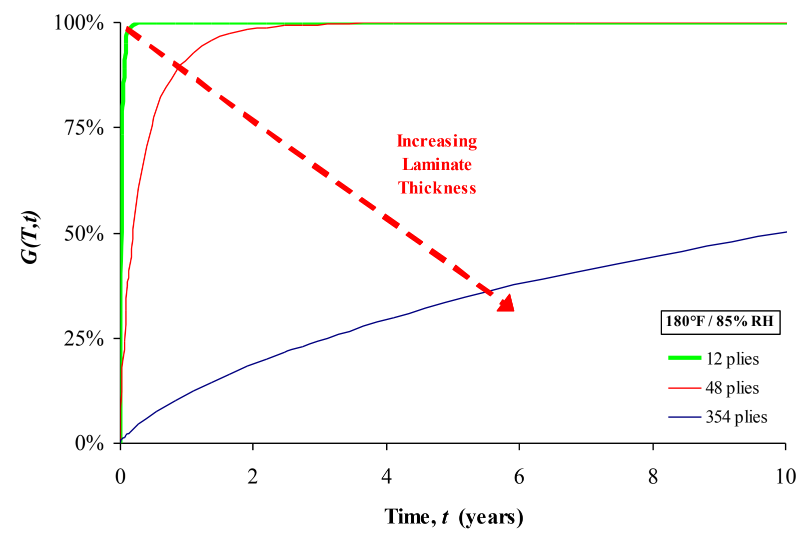
Service life Assumptions

- Assume 10 years continuously in worst case conditions (conservative!).
  - ***<u>This does not indicate a 10 year service life</u>***. Merely the worst case that would happen in 10 years with no time at altitude or other drier locations.
  - Max. saturation levels and conditioning criterion
    - Condition a representative article such that it reaches the same saturation level expected for the full scale aircraft in a worst case environment





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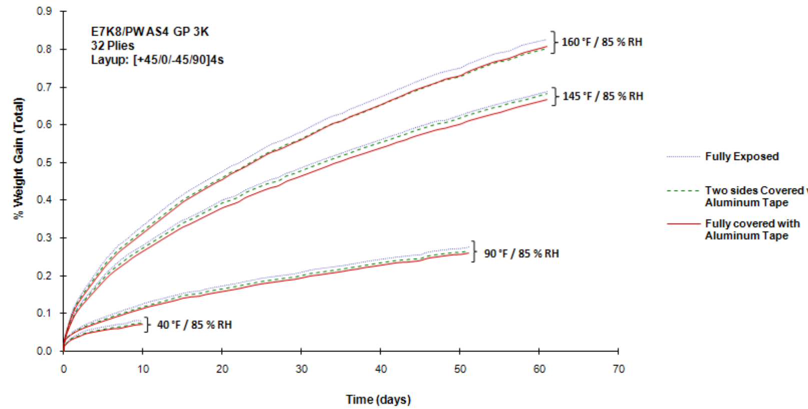
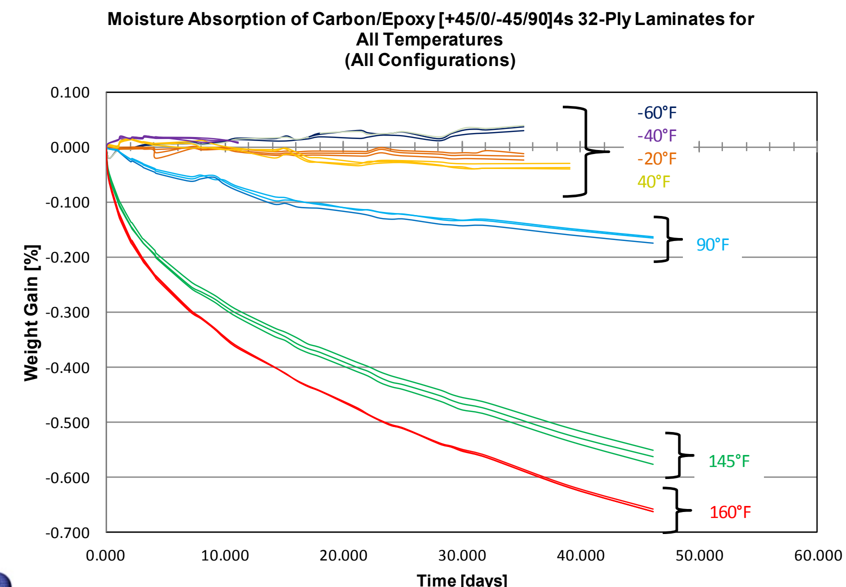
Diffusivity Constant

Chamber Temperature (°F)	Initial Dry Conditioning (180°F / 85% RH)			Initial Wet Conditioning (180°F / 0% RH)		
	Specimen Configuration			Specimen Configuration		
	Fully Exposed	Sides Covered	Fully Covered	Fully Exposed	Sides Covered	Fully Covered
-60°F				1	1	1
-40°F				1	1	1
-20°F				1	1	1
40°F	1	1	1	1	1	1
90°F	1	1	1	1	1	1
145°F	1	1	1	1	1	1
160°F	1	1	1	1	1	1
Total Specimens Required	4	4	4	7	7	7
	12			21		
	33					





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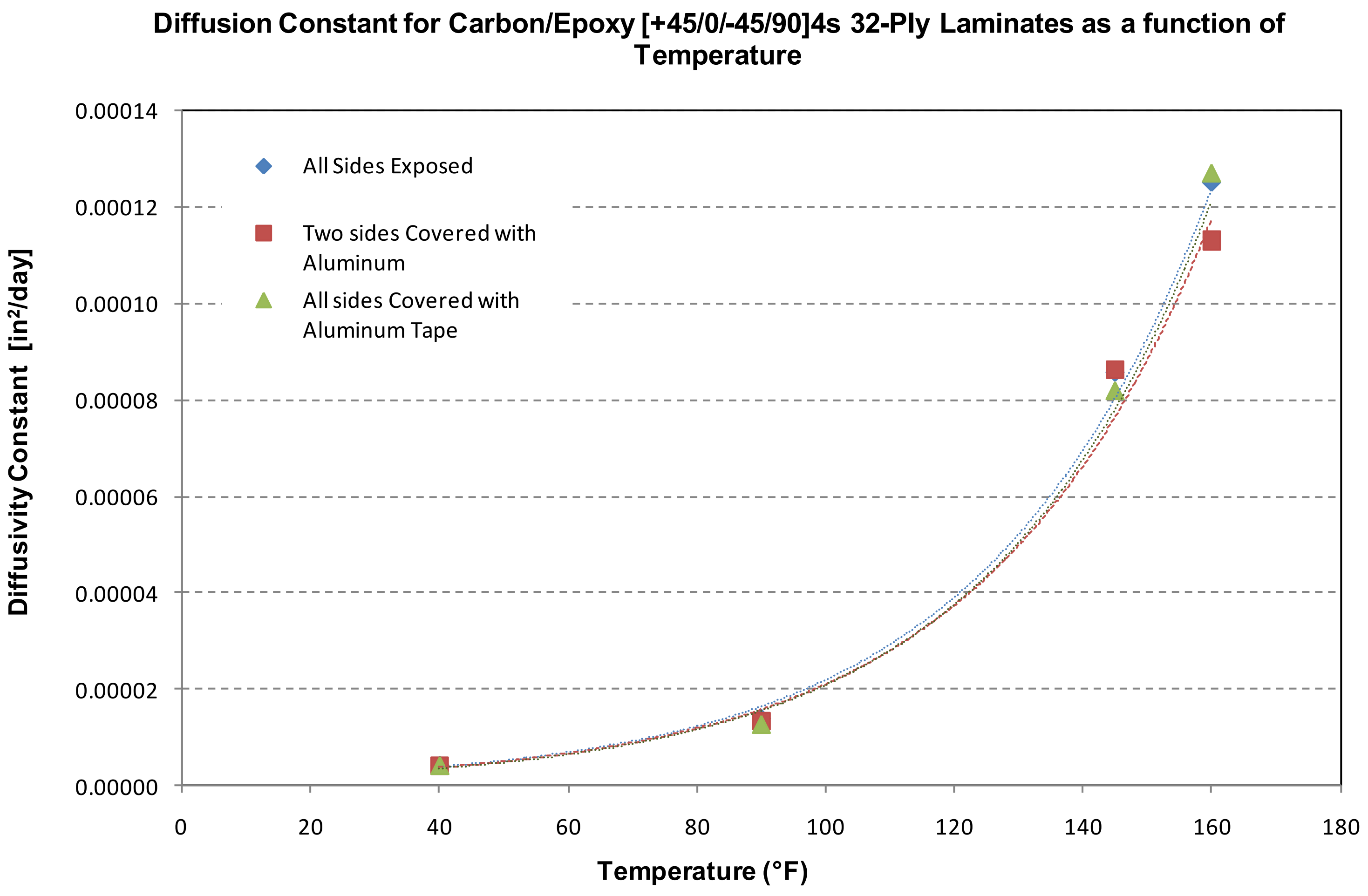
Diffusivity Constant - Absorption



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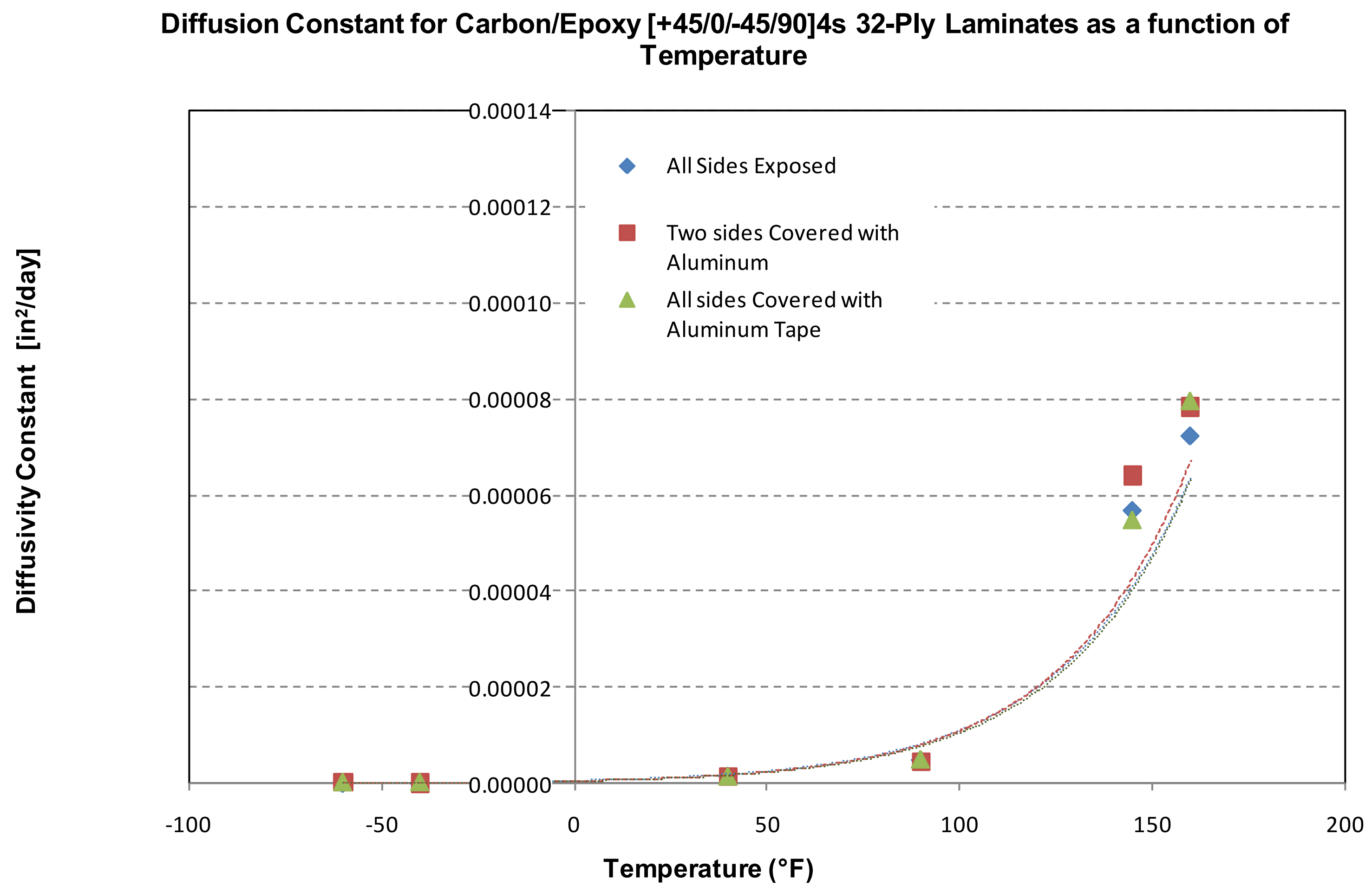
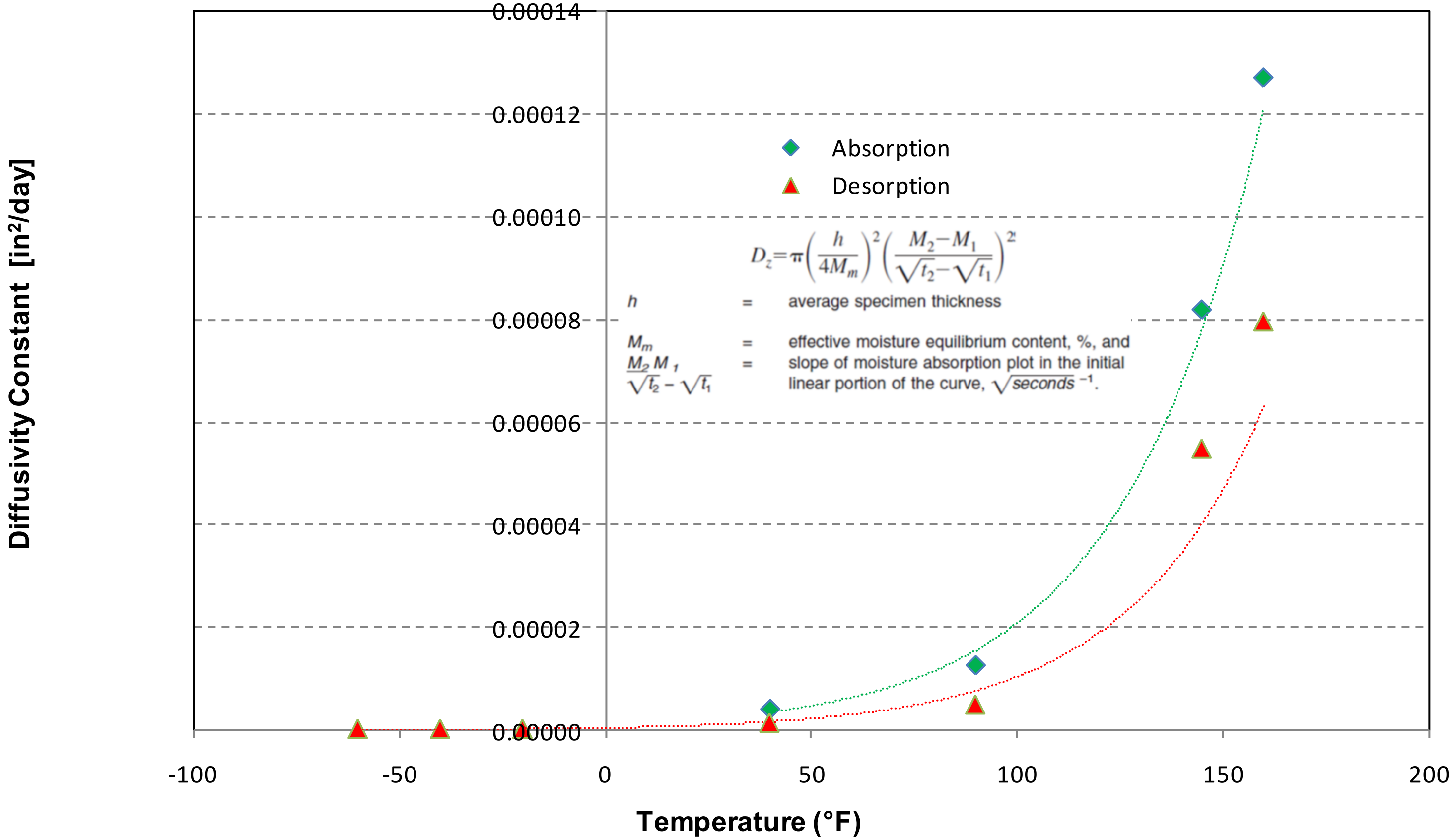
Diffusivity Constant - Desorption



Diffusivity Constant - Summary

Diffusion Constant for Carbon/Epoxy [+45/0/-45/90]4s 32-Ply Laminates as a function of Temperature



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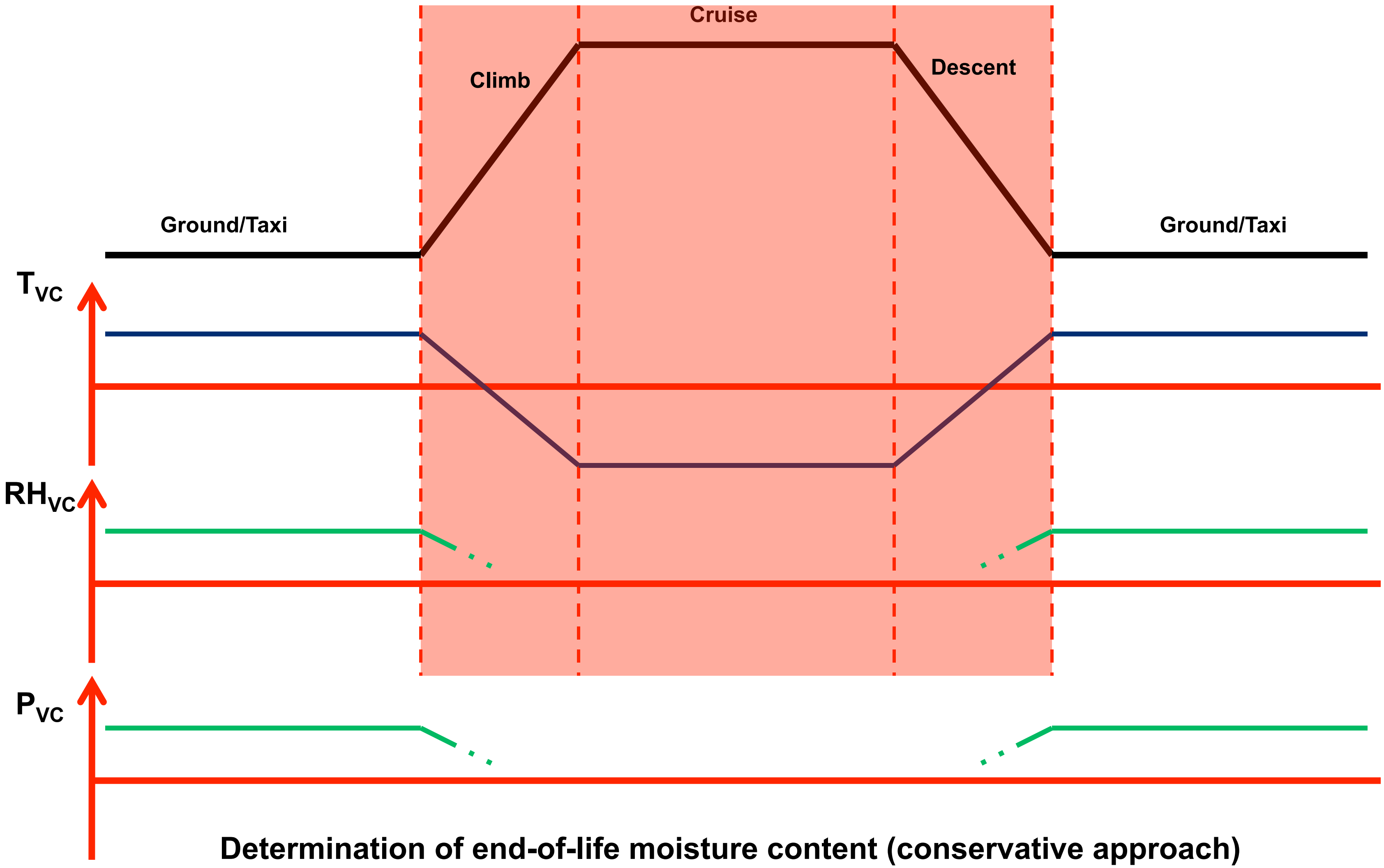
Aircraft (Fleet) Environmental Exposure



Determination of end-of-life moisture content (conservative approach)

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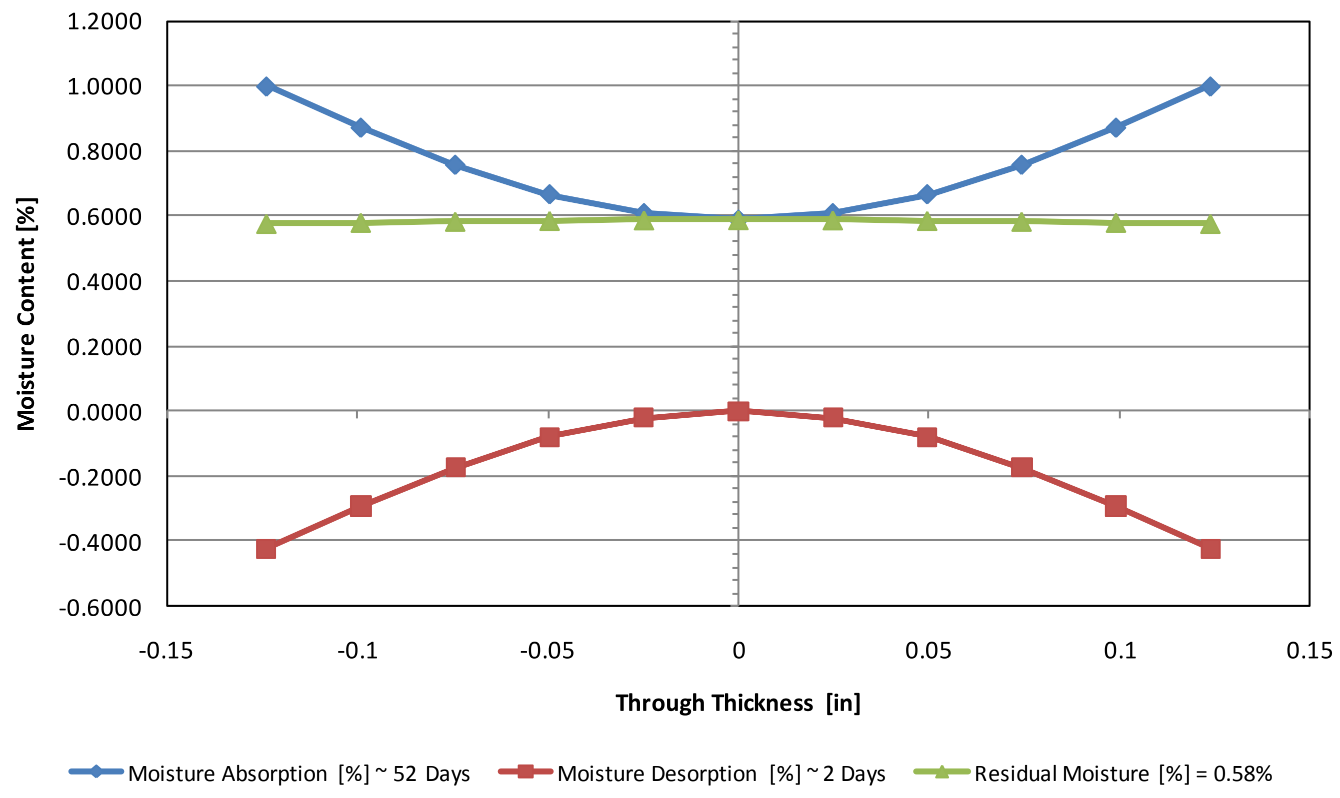
Cyclic Moisture Distribution



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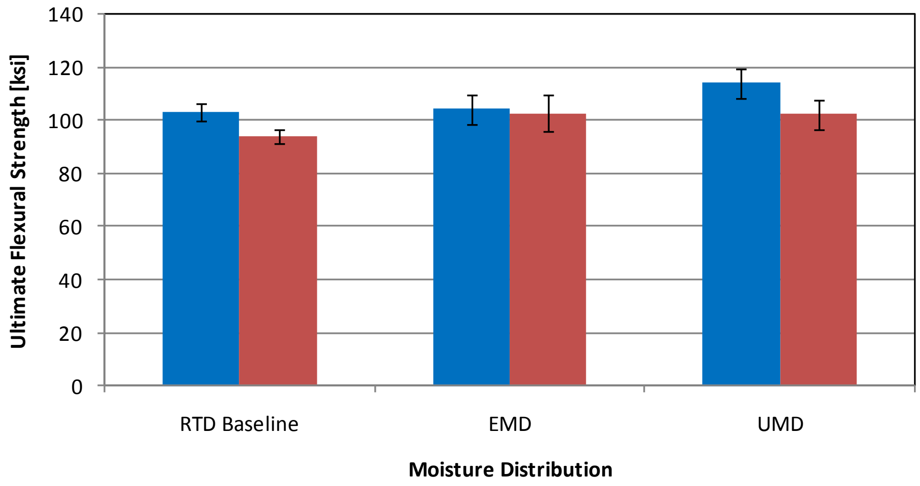
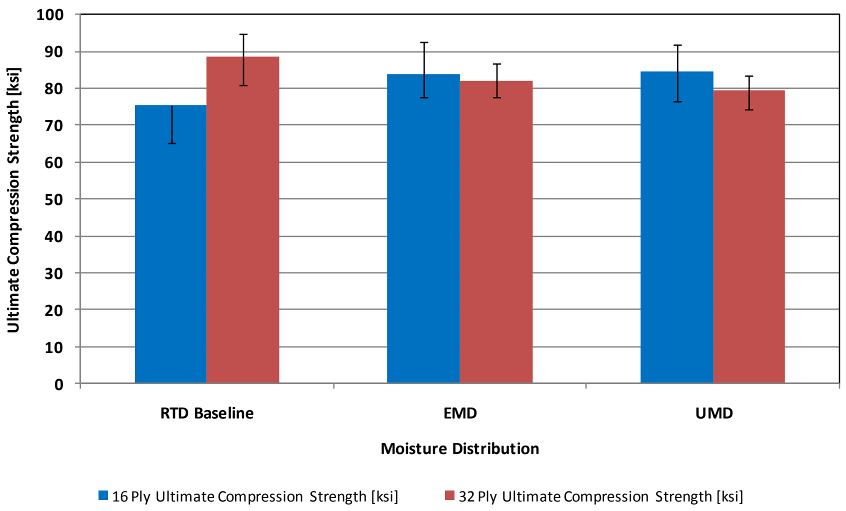
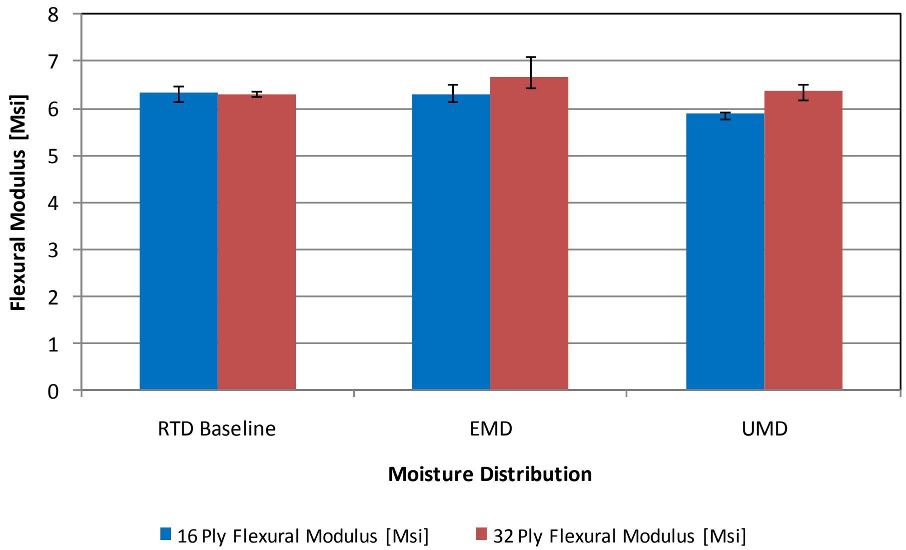
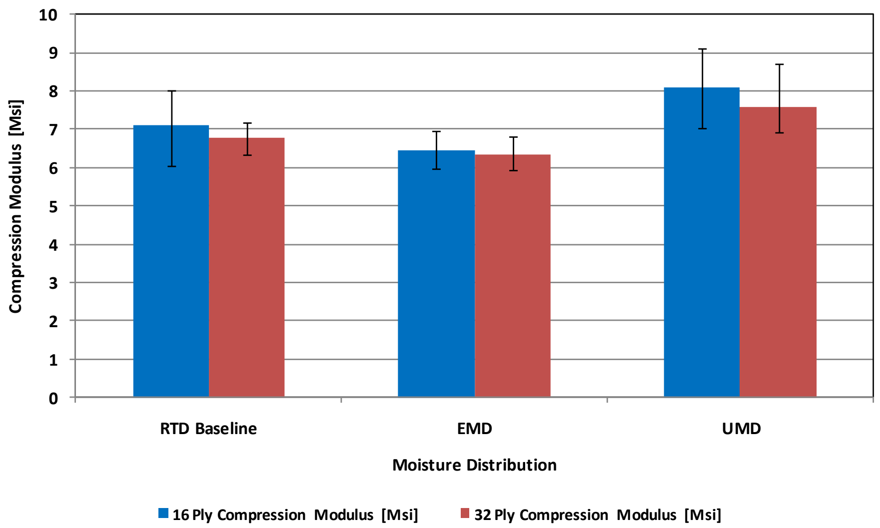
Effects Moisture Distribution TTT









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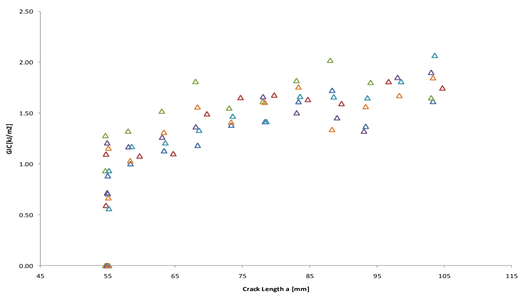
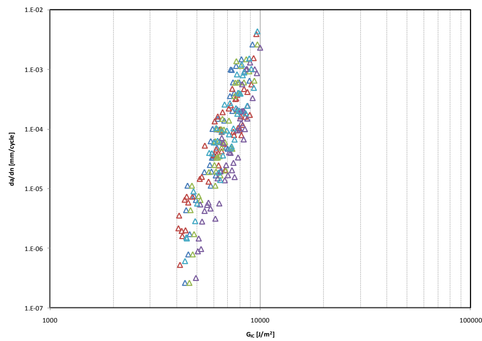
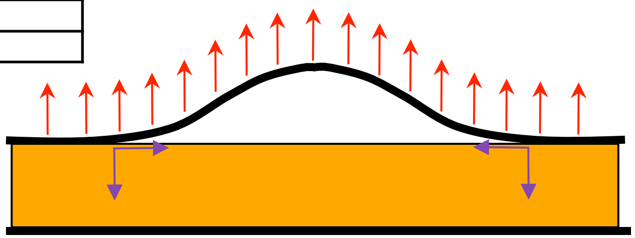
FLUID-INGRESSED SANDWICH STRUCTURE

Fluid-Ingressed Sandwich Mode I Testing

Material	Core Type	Core Thickness (in)	Facesheet (per F/C)	Cell Size (in)	Core Density	Static Baseline	Static Fluid Ingressed	Fatigue Baseline	Fatigue 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			





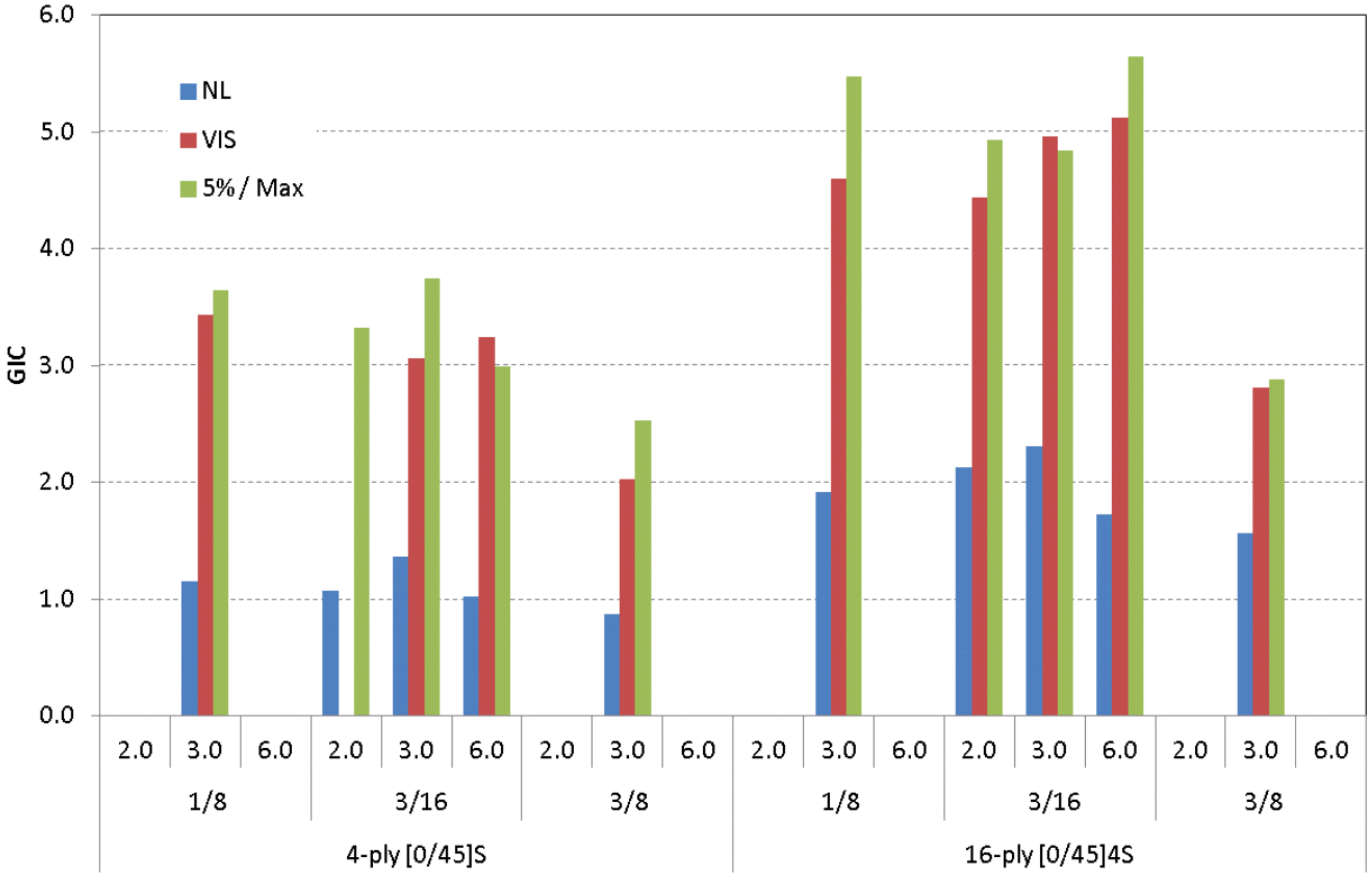


SCB Mode I RTD Summary

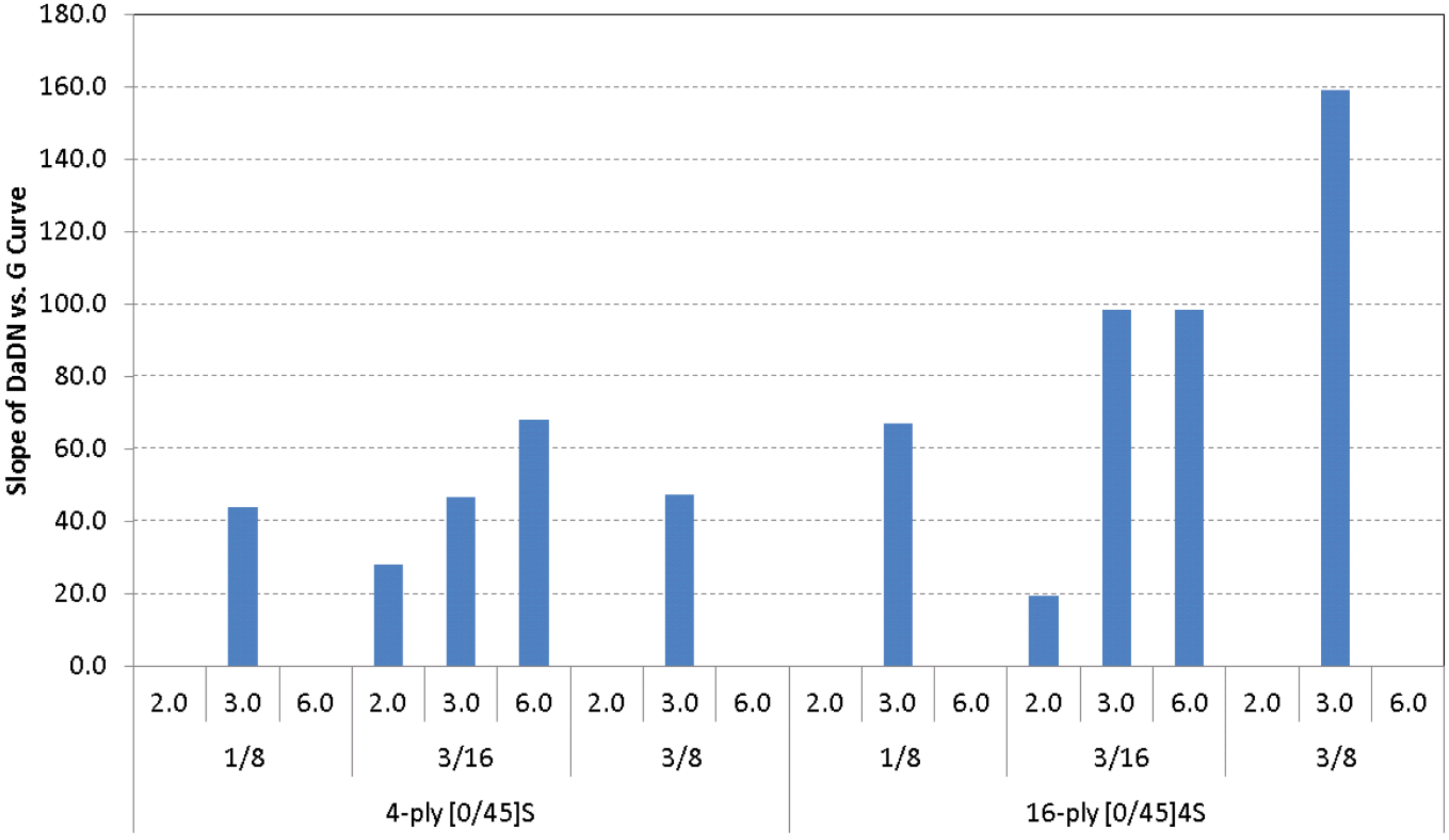
Material	Core Type	Core Thickness (in)	Facesheet	Cell Size (in)	Core Density	Static				Fatigue	
						Baseline			Fluid Ingressed	Baseline	Fluid Ingressed
						GIC (NL) [in-lb/in^2]	GIC (VIS) [in-lb/in^2]	GIC (5%/max) [in-lb/in^2]	Conditioning	Slope of the Paris Region	Conditioning
HRH-10	Hexagonal	0.5	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*		44.053	
					6.0						
				3/16	2.0	0.605	1.945	2.020	-	-	-
					2.0*	*1.067*	-	*3.317*		28.080	
					3.0	0.604	2.153	2.325	-	-	-
					3.0*	*1.362*	*3.058*	*3.740*		46.679	
					6.0	0.596	2.012	2.349	-	-	-
					6.0*	*1.020*	*3.246*	*2.993*		68.198	
				3/8	2.0						
					3.0	0.788	3.149	3.030	-	-	-
					3.0*	*0.868*	*2.028*	*2.533*		47.395	
					6.0						
			16-ply $[0/45]_{4s}$	1/8	2.0						
					3.0	1.912	4.603	5.475		67.148	
					6.0						
				3/16	2.0	2.128	4.437	4.931		19.560	
					3.0	2.305	4.961	4.842		98.307	
					6.0	1.722	5.121	5.645		98.503	
				3/8	2.0						
					3.0	1.567	2.813	2.877		159.140	
					6.0						
	OX-Core	0.5	4-ply	3/16	2.0						
					3.0	0.583	1.712	2.195	-	-	-
					3.0*	*1.088*	-	*3.131*		23.102	
					6.0						
			16-ply	3/16	2.0						
					3.0	1.541	5.483	6.017		18.959	
					6.0						

**** Indicates shortened specimens***

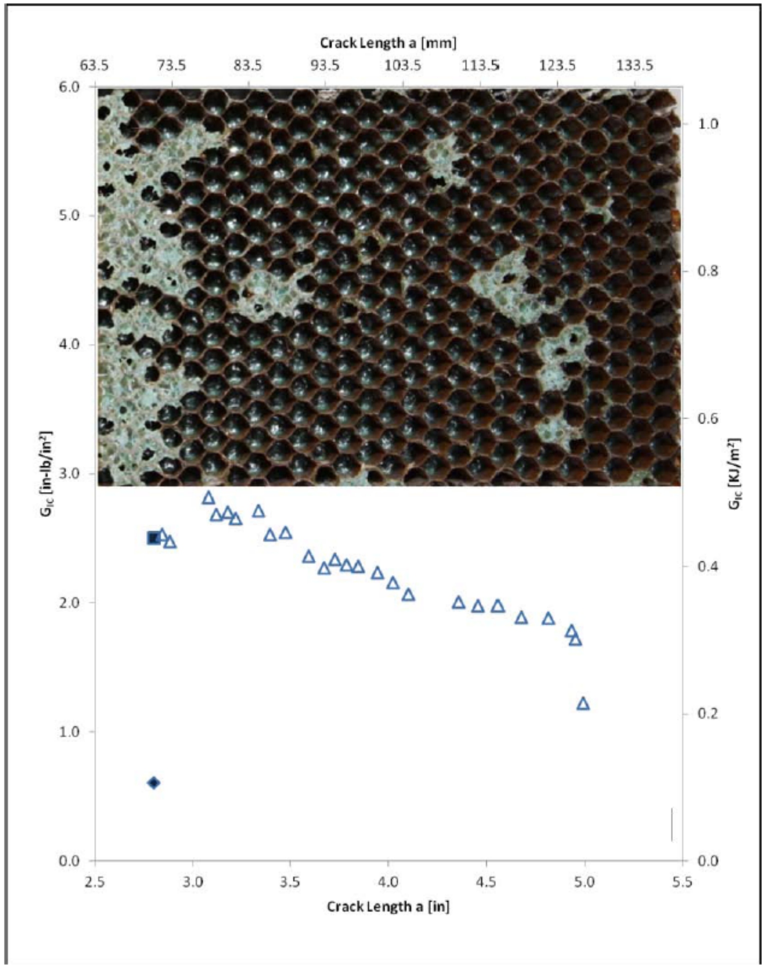
SCB Mode I RTD Summary

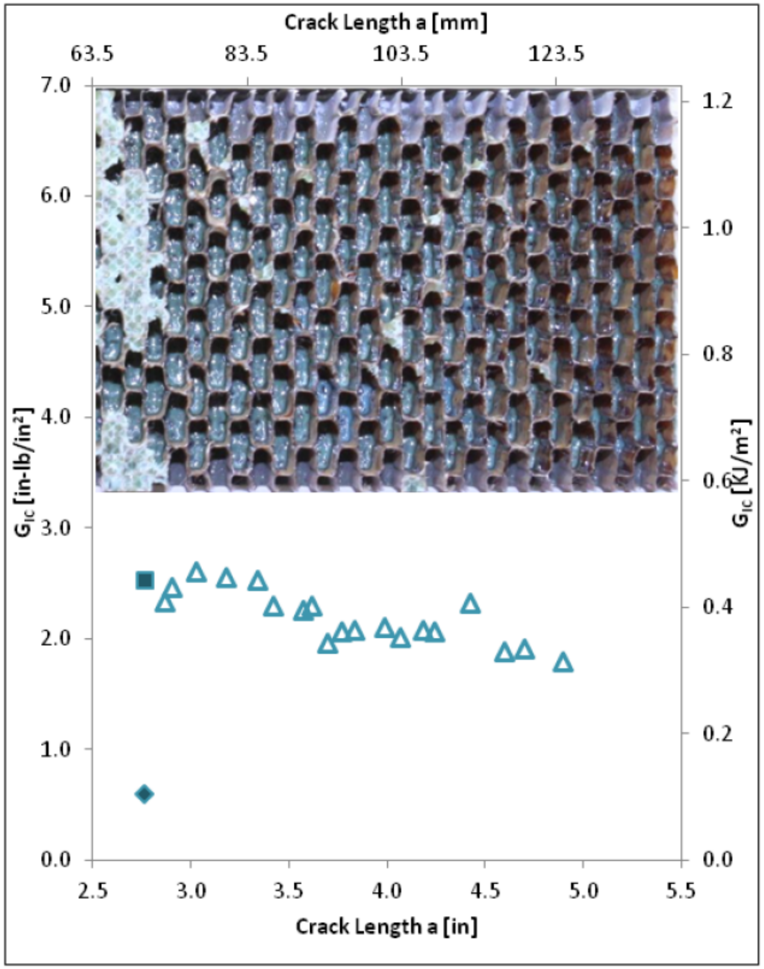


SCB Mode I (RTD) Fatigue Summary



Failure Mode(s)





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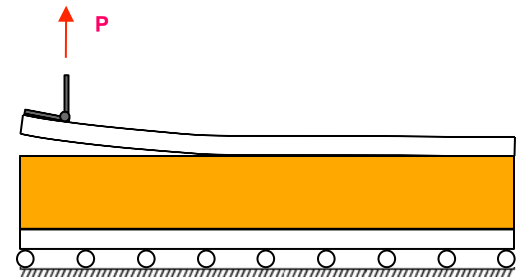
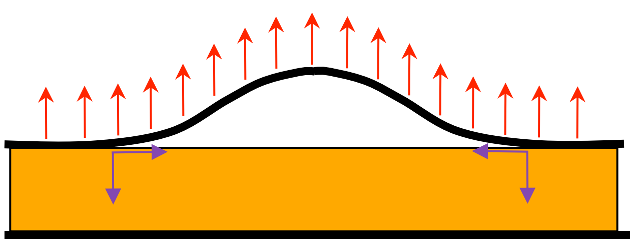
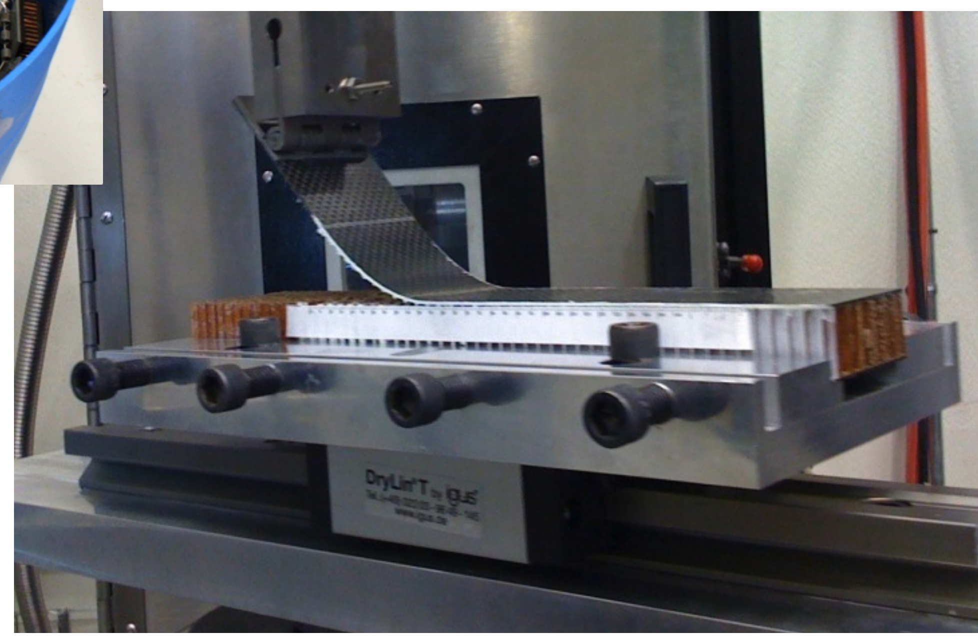
Skydrol Conditioning of SCB Specimens





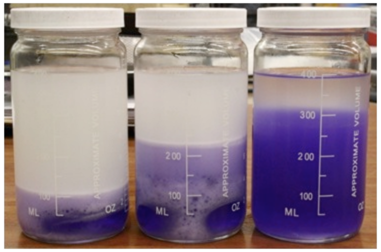


Skydrol Conditioning Study

Conditioning Timeframes	Temperature [°F]	Skydrol [%]	Water [%]
Continuous	70	75	25
		50	50
		25	75
	120	75	25
		50	50
		25	75
	160	75	25
		50	50
		25	75
Chamber till Acidity Saturate and Then Room Temp	120	75	25
		50	50
		25	75
	160	75	25
		50	50
		25	75
2 Weeks	160	50	50

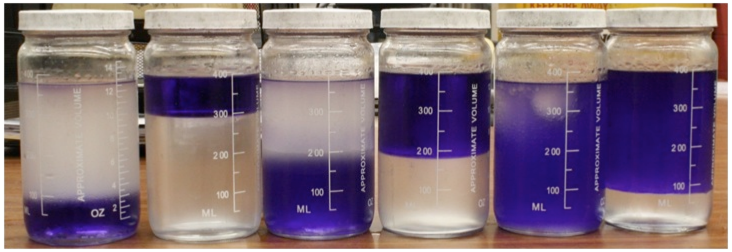
After 5 Weeks

70 °F

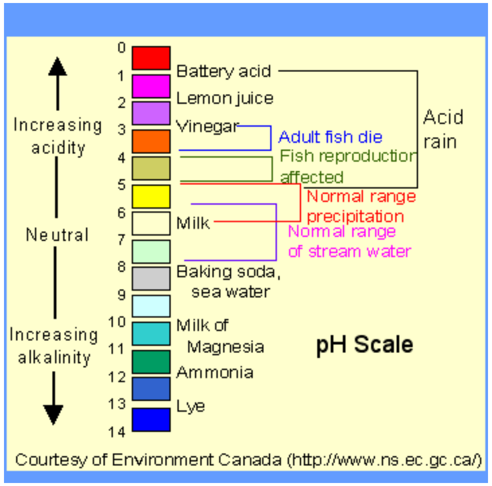


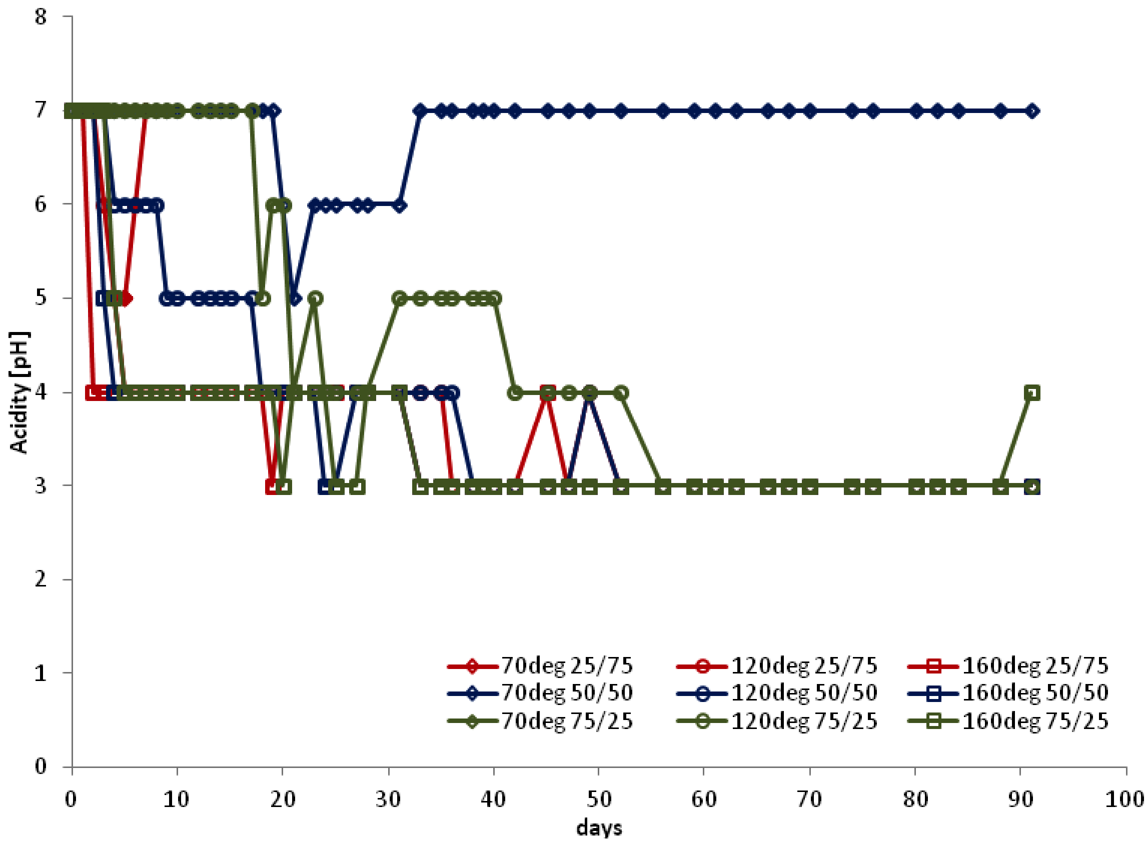
120 °F

160 °F



Skydrol Conditioning





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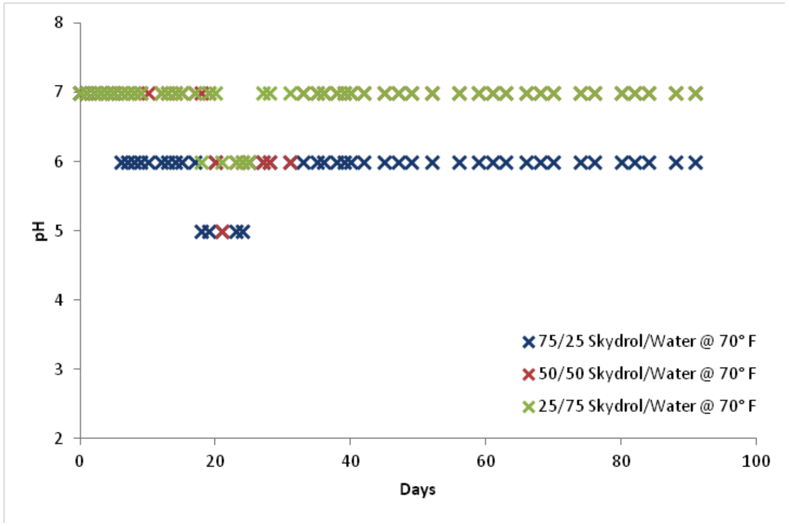
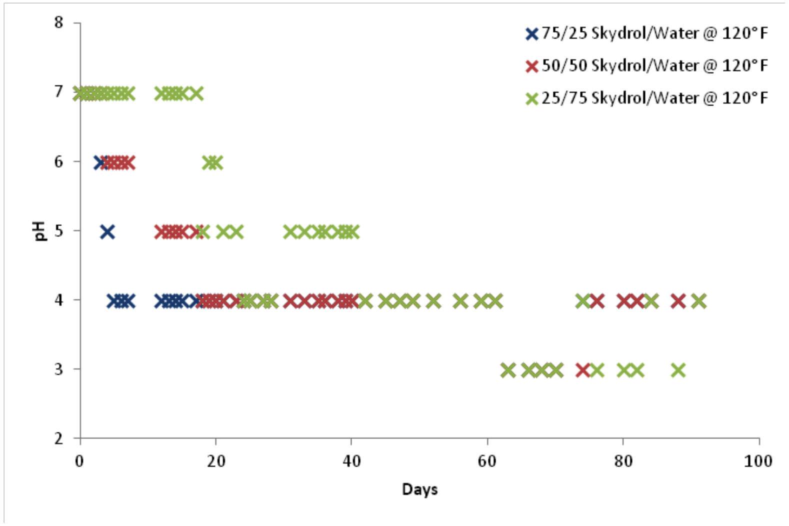
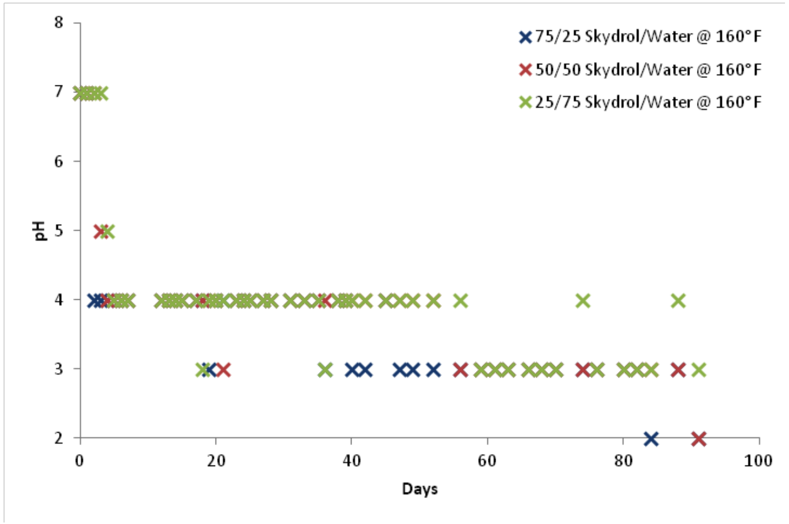
Acidity Level Monitoring

- Samples were conditioned continuously at prescribed temperature







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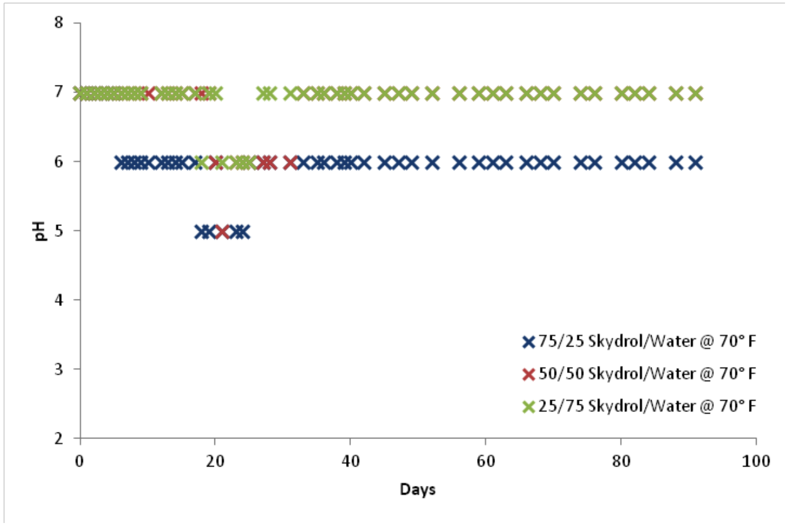
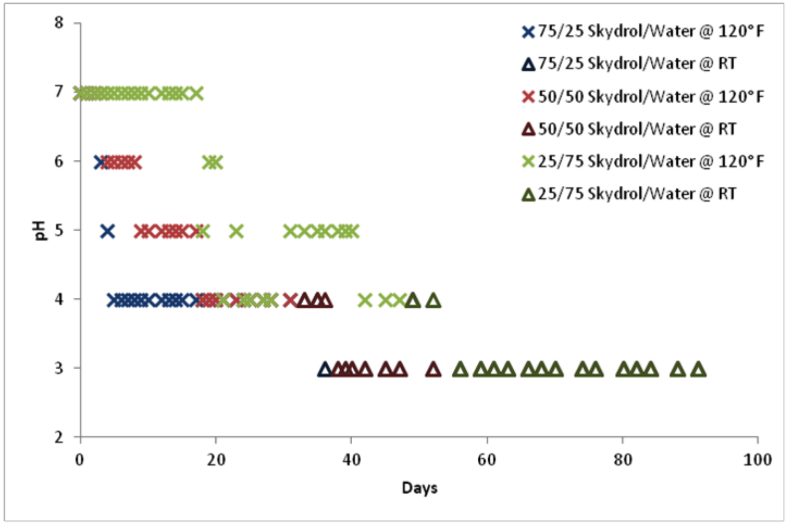
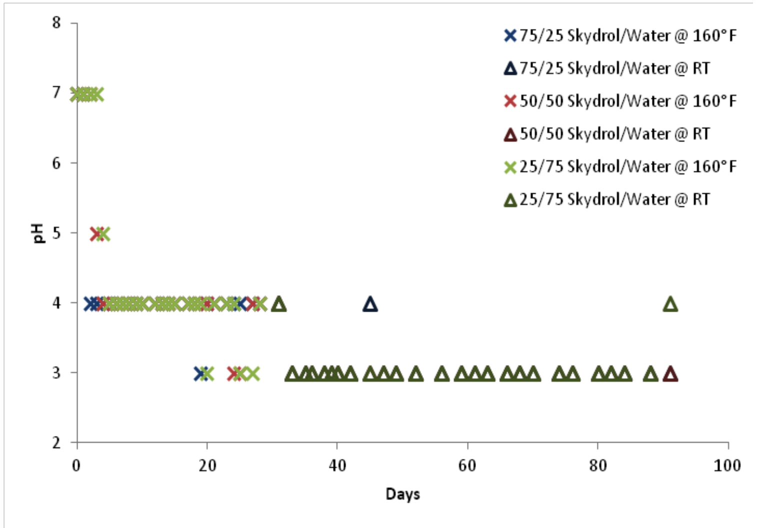
Acidity Level Monitoring

- Samples were conditioned at prescribed temperature and kept at room temperature after reaching targeted acidity level







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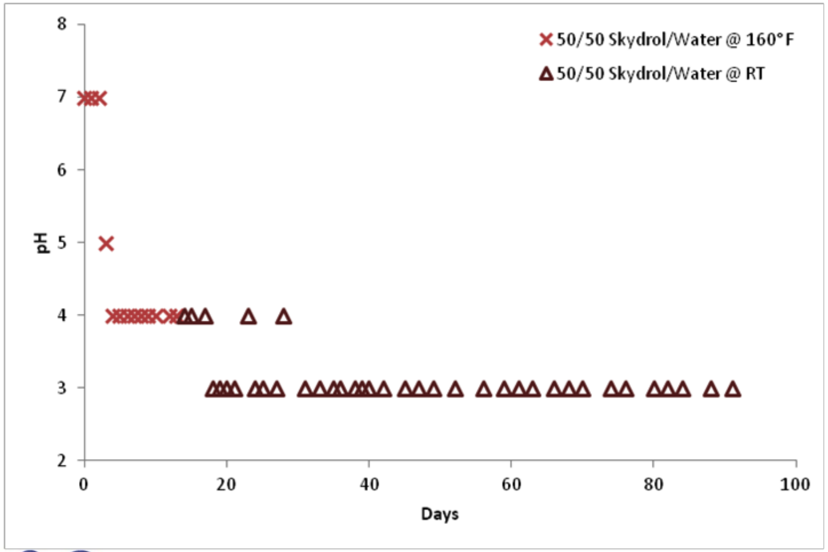
Skydrol Conditioning Procedure

- Mix the needed amount of 50% Skydrol and 50% water solution in the air tight container.
- Place the container inside the conditioning camber at 160 °F for 14 days, mixing thoroughly once a day.
- Remove the container from the conditioning camber and let set at room temperature until cooled.
- The solution should now be at 3-4 pH and will remain so for at least 90 days, if stored at room temperature.



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Summary

- Fickian Diffusion is effected by temperature, moisture concentration, and pressure
  - Environmental history on ground condition is important in tracking moisture content through the thickness of composite parts
- Guidelines for design and certification of composite structures related to environmental knockdown based on practical levels of moisture content and operational usage is in progress
- SCB Testing
  - Fluid ingression phenomenon and the progressive damage growth due to entrapped fluids in sandwich structures

Looking Forward

- **Benefit to Aviation**
  - Systematic approach for developing environmental knockdown factors based on structural details
  - Possibility of extending the methodology for life extension strategies
  - 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**
  - Test articles representing modern day composite structures
  - Environmental history data

End of Presentation.

Thank you.

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