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Effects of Moisture Diffusion in Sandwich Composite Structures

2019 Technical Review

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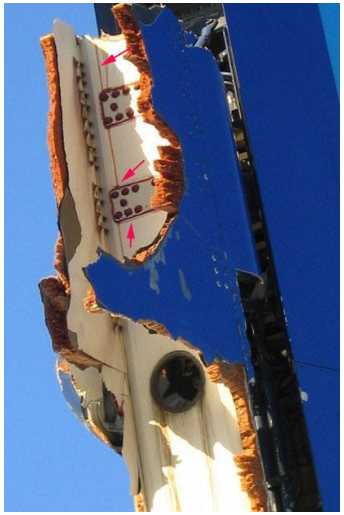
Effects of Moisture Diffusion in Sandwich Composite Structures

Motivation:

- In-service bond failures between composite facesheets and honeycomb cores have been reported



Airbus A-310 Rudder Failure

Boeing 747 upper skin disbonds

X-33 Liquid Hydrogen Tank Failure

(Photos courtesy of Ronald Krueger, National Institute of Aerospace)

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Effects of Moisture Diffusion in Sandwich Composite Structures

<u>Key Issues</u>:

- Core-to-skin disbond initiation and growth are thought to occur due to combination of factors:
    - Water ingression into core volume, followed by freeze-thaw cycles may occur due to:
        - Wicking of liquidous water through face sheet microcracks, along fiber/matrix interfaces, and/or through improper design of edge closeouts
        - Diffusion of water *molecules* through (otherwise undamaged) face sheets, resulting in increased core humidity levels
    - Pressure differences between inside and outside of unvented honeycomb cores (Ground-Air-Ground or ‘GAG’ pressure cycles)

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Investigated effects at Room Temperature during 2nd & 3rd year of study

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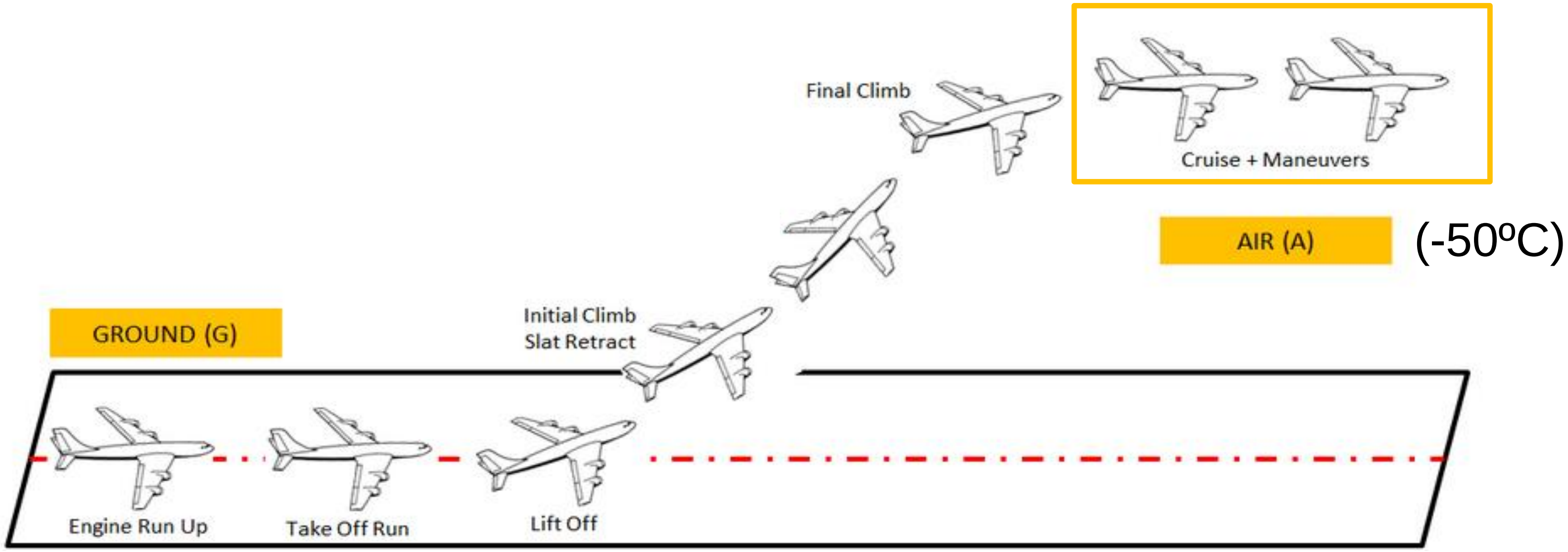
Effects of Moisture Diffusion in Sandwich Composite Structures

Objective:

Determine the effects condense-freeze-thaw-evaporate of humid air trapped with the core coupled with thermal cycles encountered by transport aircraft at flight altitudes (-50ºC)



** Sketch modified from http://www.stressebook.com/aircraft-ultimate-loads/*

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Technical approach:

- Measure critical strain energy release rate associated with sandwich face sheet/core debonding (G_c), measured before & after environmental exposure
- Consider SCB specimens with 3-, 4-, and 8-ply woven fabric face sheets and four different honeycomb cores types
- Test using the Single Cantilever Beam (SCB) geometry at -50ºC
  - Before environment conditioning – As produced specimens
  - After environment conditioning - 2-month (1440 hr) exposure to 65°C and 90%RH, causing humidity within the core volume to increase to >70%RH, followed by 150 - one-hour thermal cycles from 30°C to -50°C

Effects of Moisture Diffusion in Sandwich Composite Structures

<u>Outline of the Presentation</u>:

- Measurement of G_c associated with face sheet/core bond failures in sandwich structures:

  - Overview of SCB test geometry

  - Summary of the Single-Cantilever Beam (SCB) tests performed during the 3rd year of study *(Sept ‘17-Sept ‘18)*

  - Results from on-going 4th year of study:
    - As-produced measurements tested at -50ºC (completed)
    - Humidity measurements (ongoing)
    - Thermal cycling (planned)

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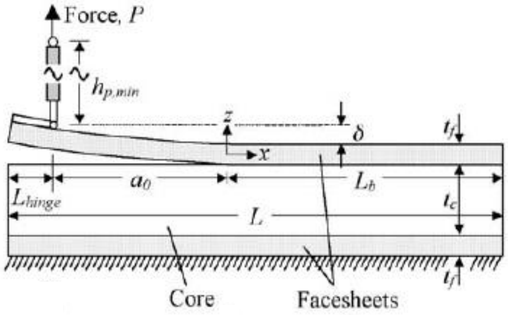
Single-Cantilever Beam (SCB) Test Geometry:
(Summary of test procedure)



a) Sawcut used to produce starter crack
b) Crack propagated in the ribbon (L) direction of core
c) Crack tip location monitored by visual inspection
d) Pre-crack: Initial natural crack created by crosshead upward movement at a rate of 0.5 mm/min, until a ~5 mm crack had formed; the specimen was then unloaded
e) Load Cycle 1: The crosshead was then moved upward at a rate of 30 mm/min until the crack has grown by ~10 mm; the specimen was then unloaded at 30 mm/min
f) Load Cycle 2: Step (e) was repeated once more
g) The critical strain energy release rate G_c was determined using the "area method", based on load-displacement curves measured during Cycles 1 & 2

** Sketch extracted from: Ratcliffe, J.G., and Reeder, J.R., "Sizing a Single Cantilever Beam Specimen for Characterizing Facesheet-Core Debonding in Sandwich Structure", Journal of Composite Materials, Vol 45 (25), pp 2669-2684, (2011).*

Effects of Moisture Diffusion in Sandwich Composite Structures

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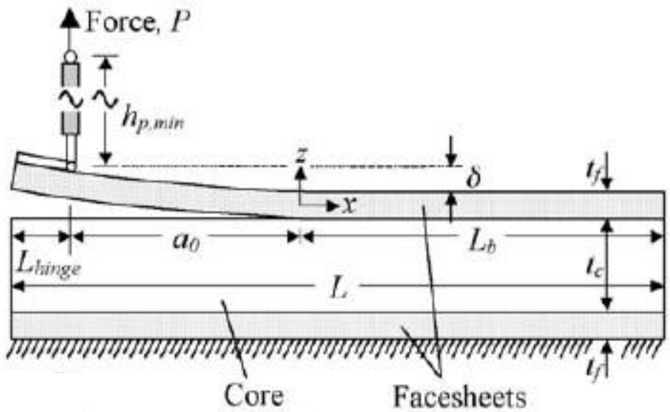

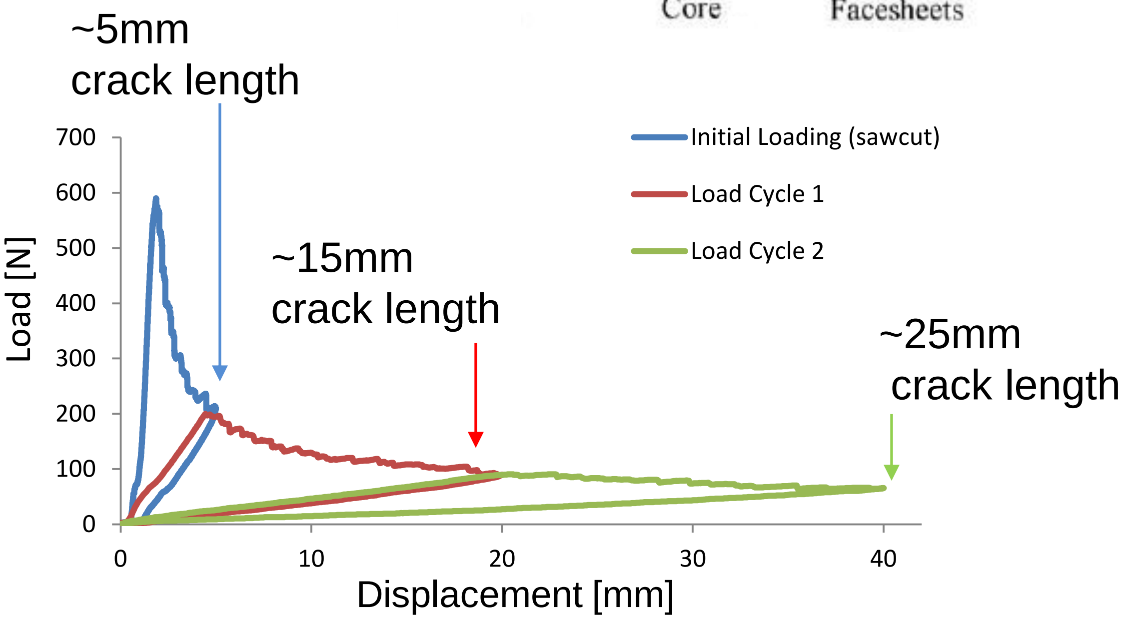

- Typical load-displacement curves measured during a SCB test
- The critical strain energy release rate was calculated using the so-called area method:

$$G_c = \frac{\Delta U}{B \Delta a}$$

where:

ΔU = area defined by the load-displacement envelope

B = specimen width

Δa = crack extension

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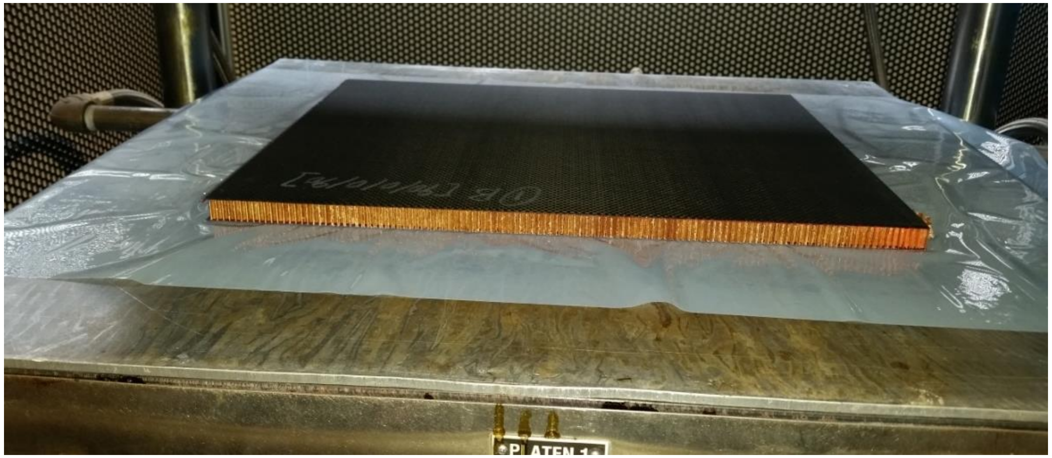
Producing Sandwich Test Panels:

- Face sheets were cured in an autoclave
- Parent panels were then produced by bonding the face sheets to honeycomb cores using thin film adhesive and a hot press SCB specimens were machined from the "parent" panels



Sandwich Test bonded and cured using the hot press- Wabash Model G50H-24-BCLX hot press

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Single-Cantilever Beam (SCB) Test Specimens:

Component	Description	Product Designation
Facesheet panels	Carbon/Epoxy plane weave prepreg:	Cytec (Solvay) T300/970 3k PW
	Three-ply: $[0/45/0]_T$	
	Four ply: $[0/90]_s$	
	Eight ply: $[0/45/90/45]_s$	
Core Materials	Nomex 48 kg/m^3 honeycomb core, 12.7 mm thick (3 lb/ft^3; 0.5 in)	Hexcel HRH-10-1/8-3
	Nomex 48 kg/m^3 honeycomb core, 25.4 mm thick (3 lb/ft^3; 1.0 in)	Hexcel HRH-10-1/8-3
	Nomex 128 kg/m^3 honeycomb core, 12.7 mm thick (8 lb/ft^3; 0.5 in)	Hexcel HRH-10-1/8-8
	Kevlar 48 kg/m^3 honeycomb core, 12.7 mm thick (3 lb/ft^3, 0.5 in)	Hexcel HRH-36-1/8-3
Adhesive	Thin film adhesive	3M Scotch-Weld AF 163-2k

SCB specimens machined from these panels tested at -50ºC for two conditions:

(a) As produced (48 specimens)

(b) Following exposure to elevated humidity and thermal cycling (48 specimens)

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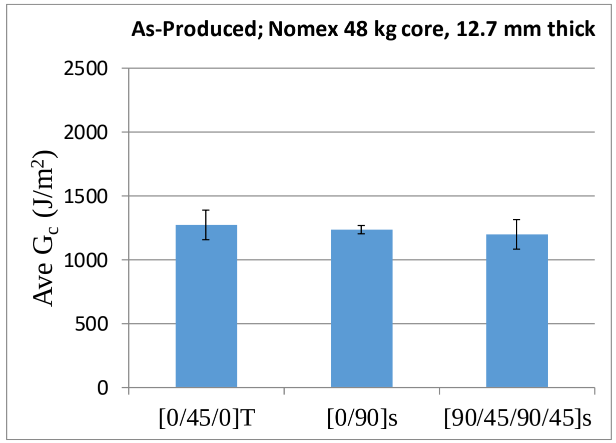
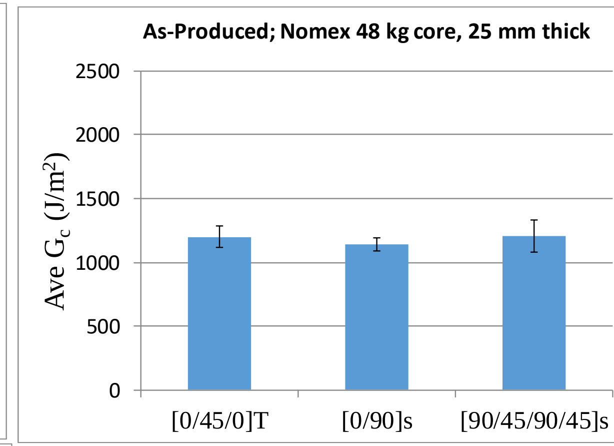
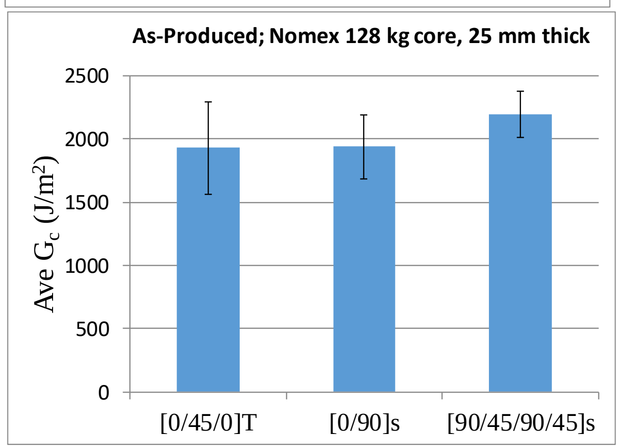
<u>SCB test conducted on as produced samples at room temperature (RT):</u>

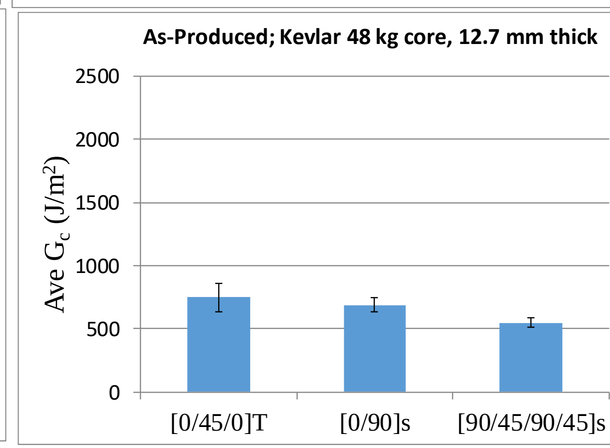
<u>Measured trends:</u>

- G_c is nearly independent of core and facesheet thickness
- G_c increases with an increase in core density
- G_c is significantly lower for Kevlar vs Nomex core









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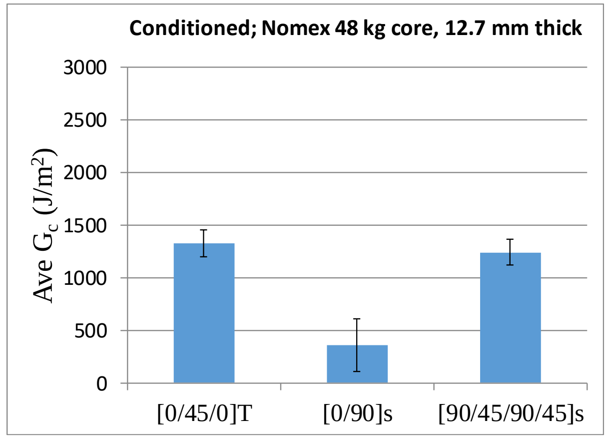
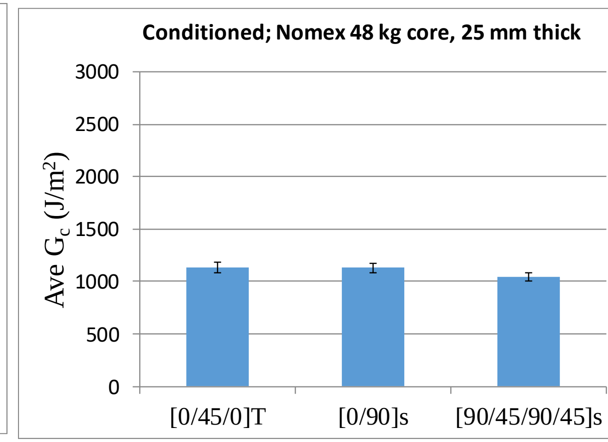
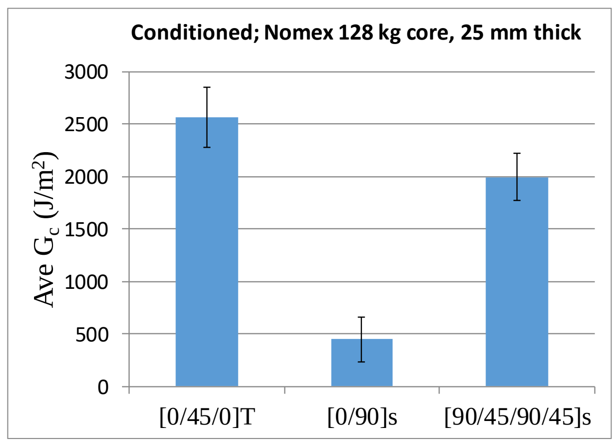
SCB test conducted on as environment conditioned samples at RT:

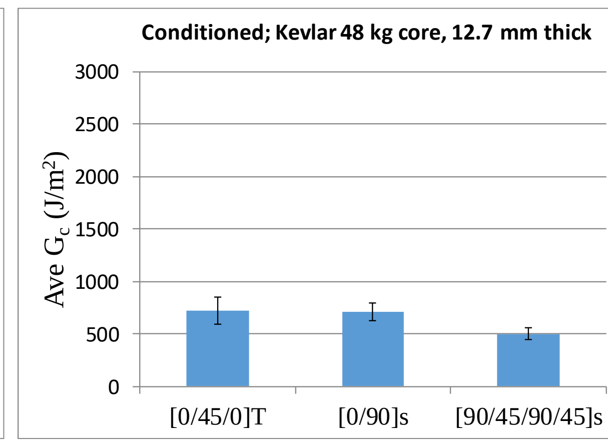
Measured trends:

- Confounding trends…for some facesheet/core combinations environmental conditioning led to erratic and inconsistent behaviors, but for others conditioning had little or no effects









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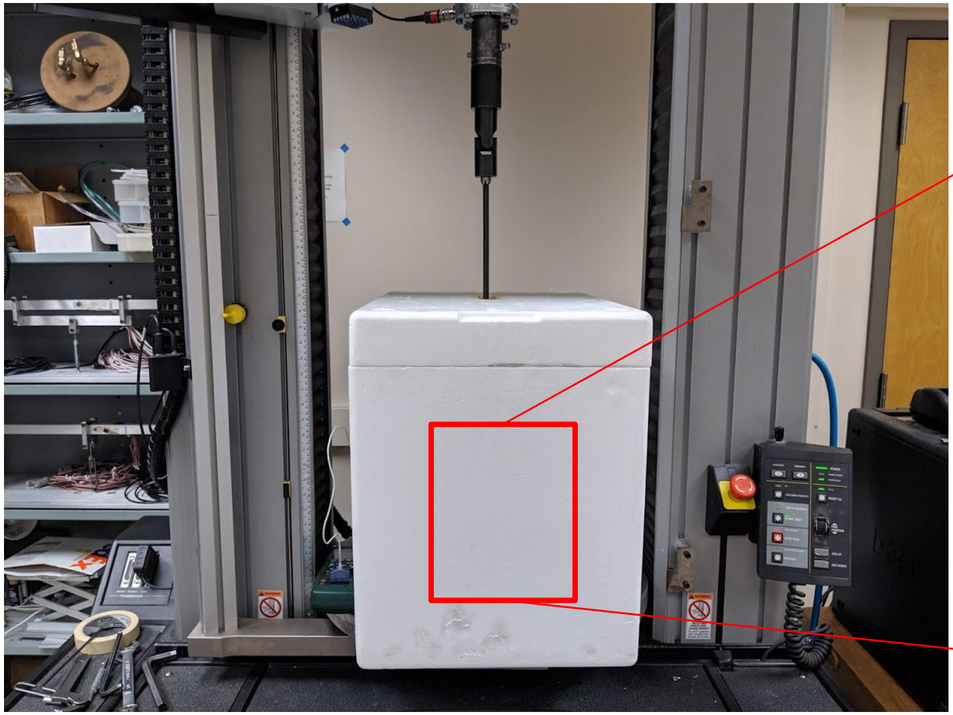
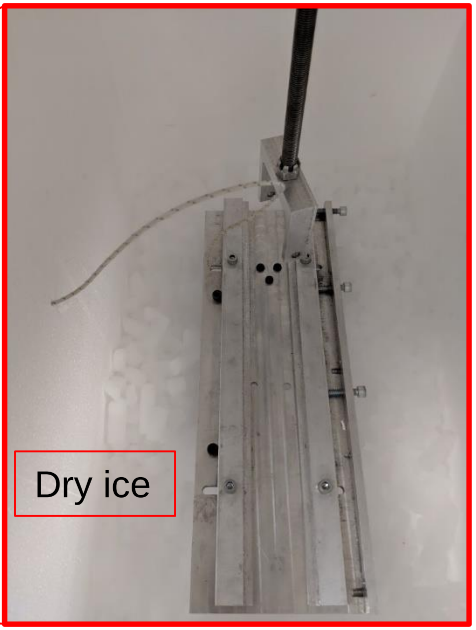
Test setup:



Styrofoam box setup in Instron 5585H



UW SCB test fixture immersed in a bed of dry ice

- A Styrofoam box of 1” thickness was used to maintain the environment at ~ -50ºC

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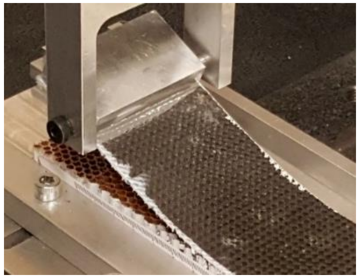
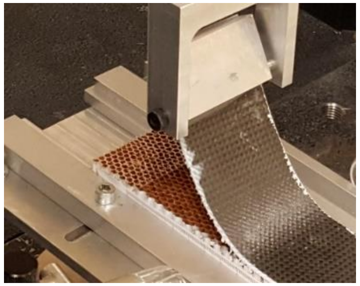
Test setup:

Thermotron Model S.12 Temperature Chamber

Specimen at -50ºC





- To minimize condensation on specimens, an environment chamber was used to maintain the specimens at -50ºC
- Crack growth was visually inspected upon completion of each load loop

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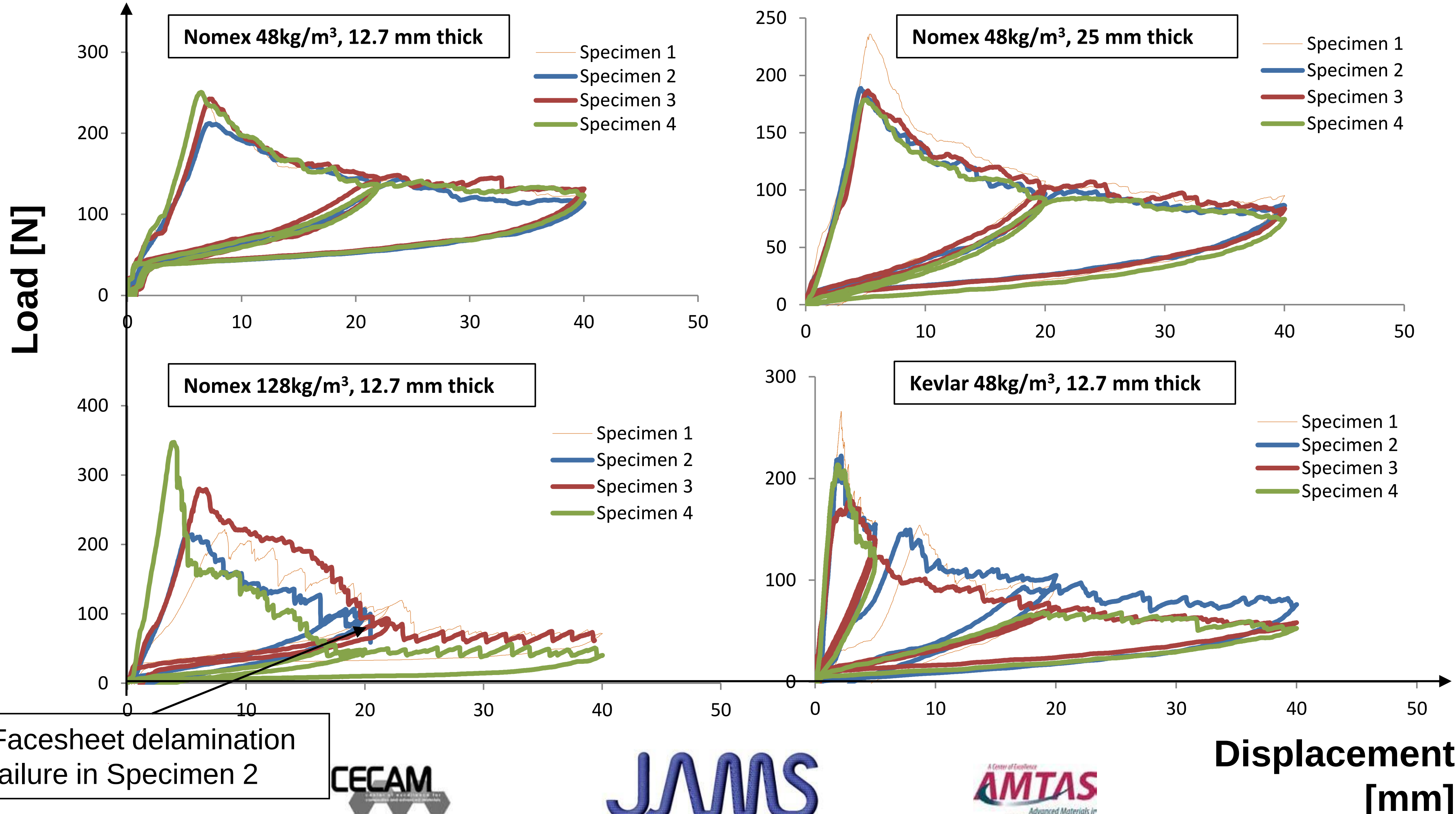
Raw Data Collected for As-Produced [0/45/0]$_T$ tested at -50ºC

(Superimposed data from four individual tests / type)



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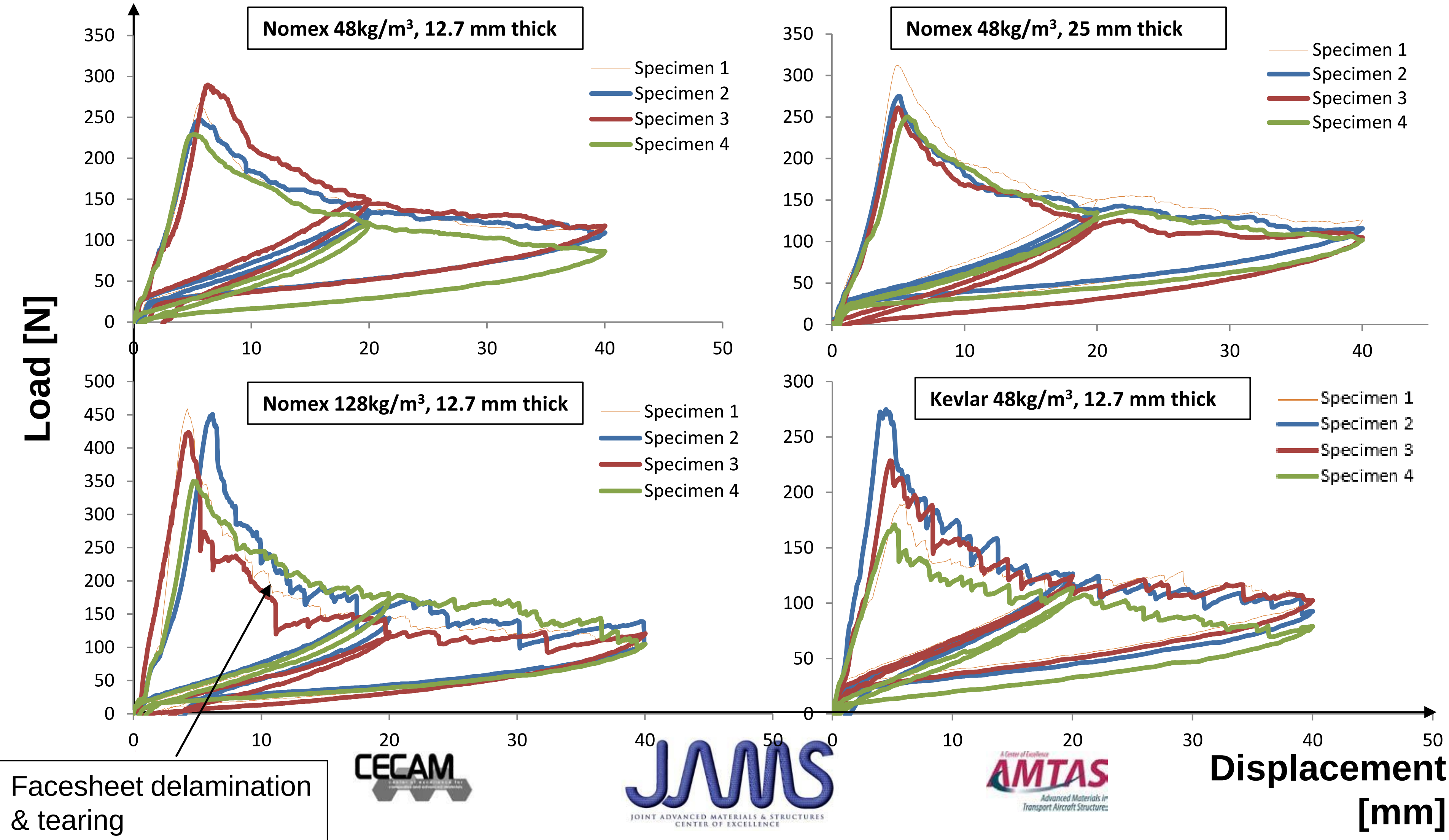
<u>Raw Data Collected for As-Produced **[0/90]$_s$** tested at -50ºC</u>

(Superimposed data from four individual tests / type)



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Raw Data Collected for As-Produced [0/45/90/45]$_S$ tested at -50ºC

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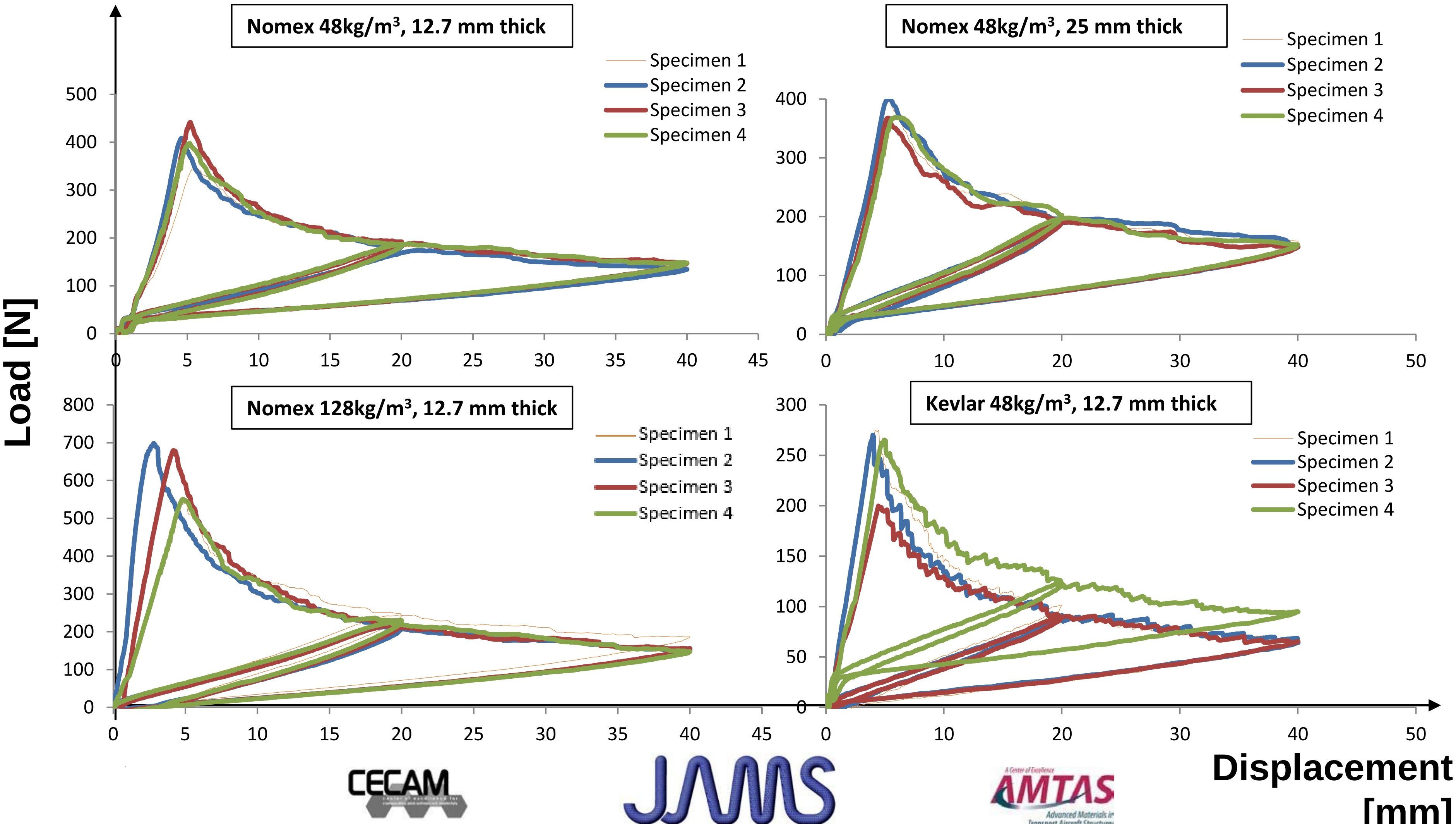

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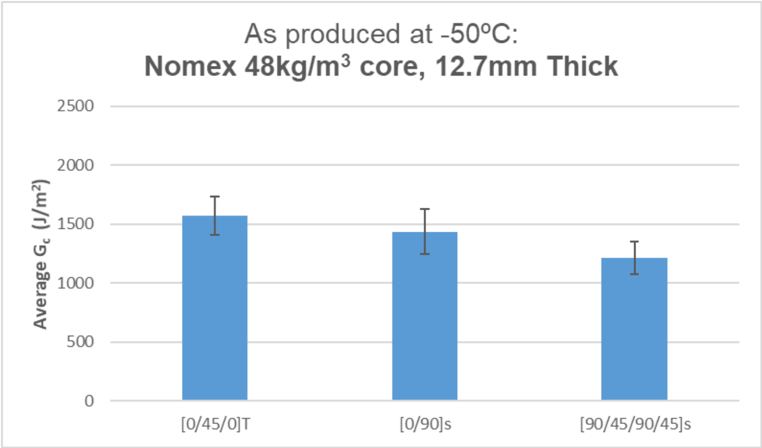
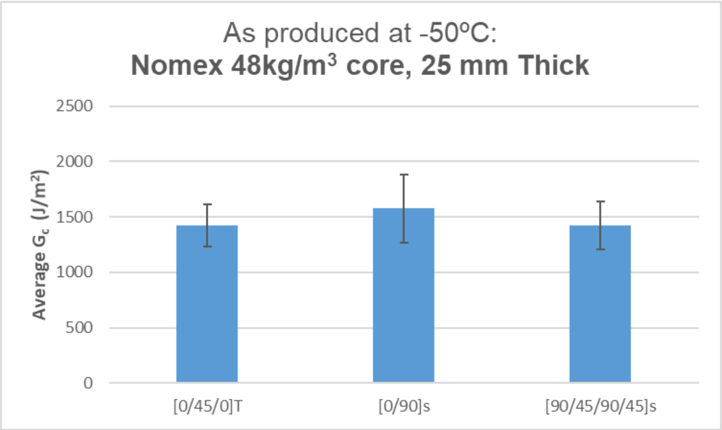
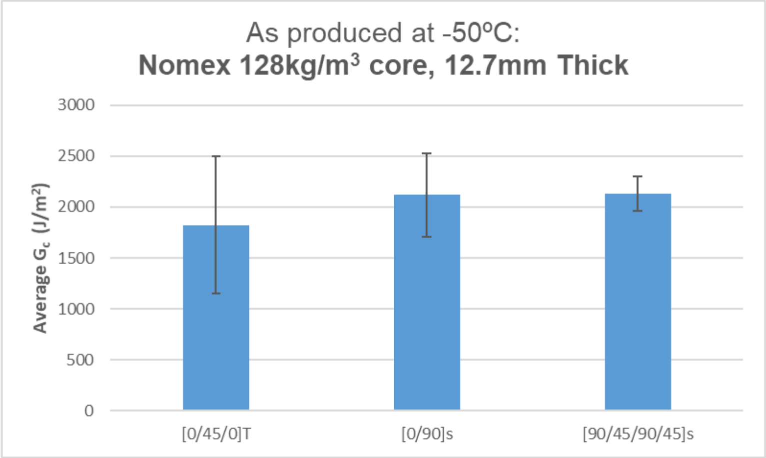
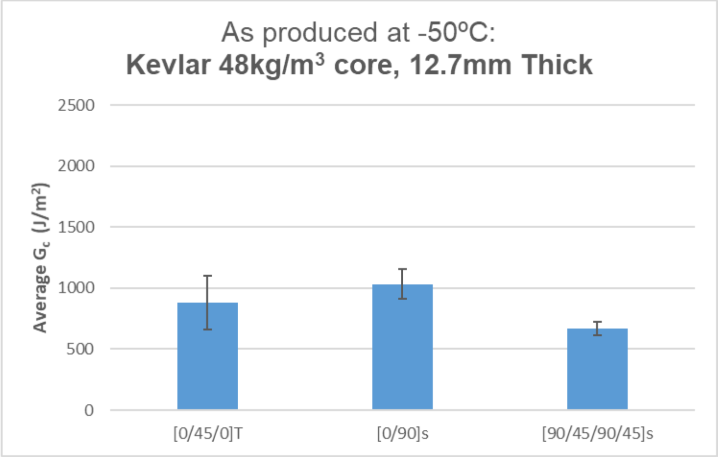
<u>G_c Measured for As-Produced Specimens tested at -50ºC</u>

(Average and std deviation, based on 4 replicate tests)









Effects of Moisture Diffusion in Sandwich Composite Structures

Discussion:

(As Produced specimens at -50ºC)

G_c is nearly independent of core and facesheet thickness:

- For 48 kg/m^3 Nomex core: average G_c (24 specimens) = 1439.3± 201.6 J/m^2
- For 128 kg/m^3 Nomex core: average G_c (12 specimens) = 2026 ± 418.3 J/m^2

G_c increases with an increase in core density:

- Average G_c measured for 128 kg/m^3 Nomex core was 40.75% higher than that measured for 48 kg/m^3 Nomex core

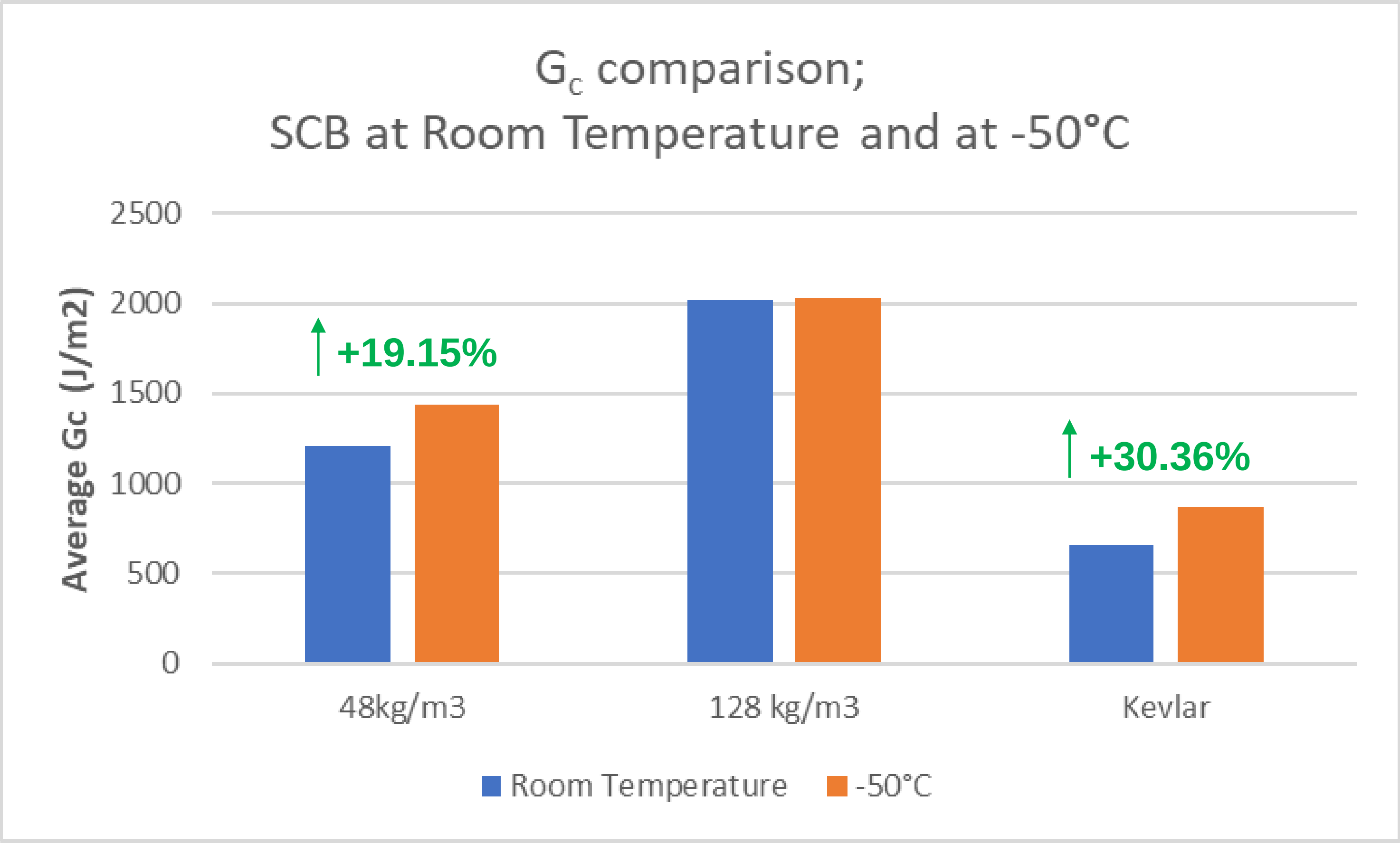
G_c is significantly lower for Kevlar vs Nomex core:

For 48 kg/m^3 cores the average G_c measured for Nomex and Kevlar cores was 1439.3 J/m^2 and 861.67 J/m^2, respectively, a decrease of 40.1%

Effects of Moisture Diffusion in Sandwich Composite Structures

Discussion:

(Comparisons between as Produced specimens tested RT & at -50ºC)



Effects of Moisture Diffusion in Sandwich Composite Structures

<u>Environmental Conditioning</u>

Exposure to elevated temperature and humidity

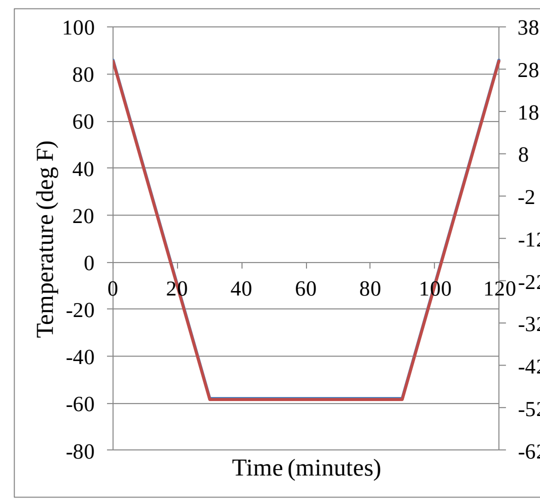
• 3-ply laminates approaching 80%RH; thermal cycling will begin soon

• Thermal cycling of 4- and 8-ply laminates will begin when core humidity ~80%RH

• SCB tests of environmentally-conditioned specimens performed after ~100 thermal cycles

Cincinnati Sub-Zero "Tundra" Environmental Conditioning Chamber

Thermotron Model S.12 Temperature Chamber



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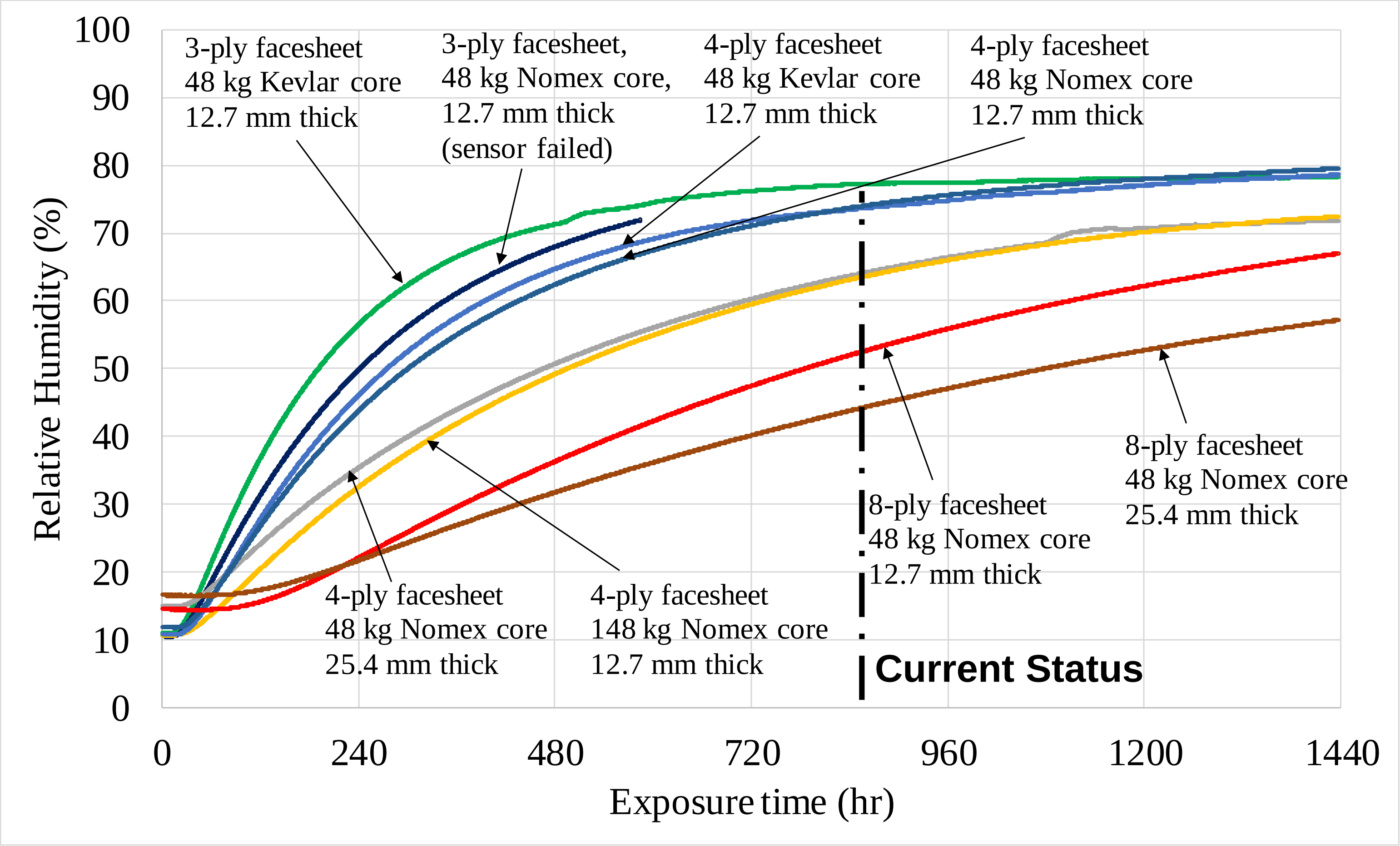
<u>Environmental Conditioning</u>

Exposure to elevated temperature and humidity



Effects of Moisture Diffusion in Sandwich Composite Structures

Benefit to Aviation:

- Will help to clarify mechanism(s) leading to initiation and growth of skin-core disbond in sandwich structures

- Will contribute to efforts to establish standard test protocols and data reduction practices for SCB testing of sandwich specimens

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Thank You!

Questions, Comments, Suggestions?

End of Presentation.

Thank you.

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