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Effects of Moisture Diffusion in Sandwich Composites

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2016 Fall AMTAS Meeting
UW Center for Urban Horticulture

Effects of Moisture Diffusion in Sandwich Composites

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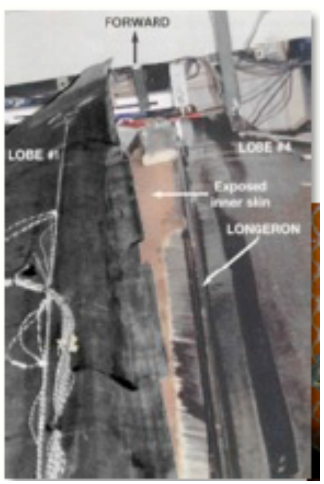
Motivation and Key Issues:

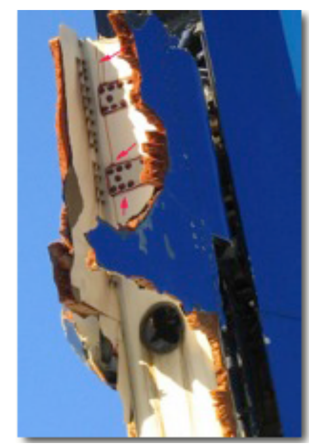
- In-service bond failures between composite facesheets and honeycomb cores have been reported

X-33 Liquid Hydrogen Tank Failure



Boeing 747 upper skin disbonds

Airbus A-310 Rudder Failure



(Photos courtesy of Ronald Krueger, National Institute of Aerospace

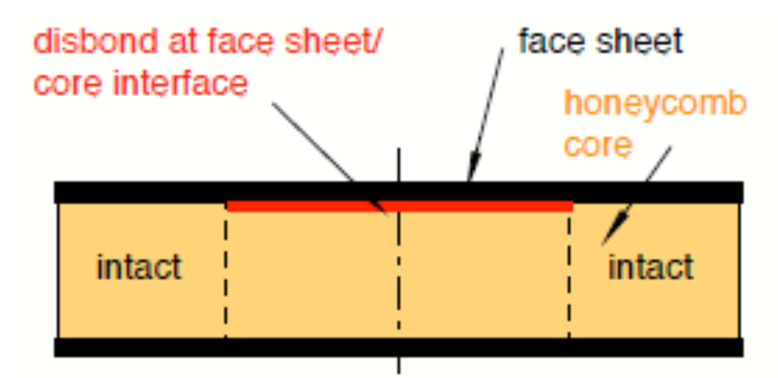
Effects of Moisture Diffusion in Sandwich Composites

<u>Motivation and Key Issues</u>:

- Disbond initiation and growth is not completely understood, but is thought to occur due to combination of factors:
  - Pressure differences between inside and outside of unvented honeycomb structures (Ground-Air-Ground or ‘GAG’ pressure cycles)

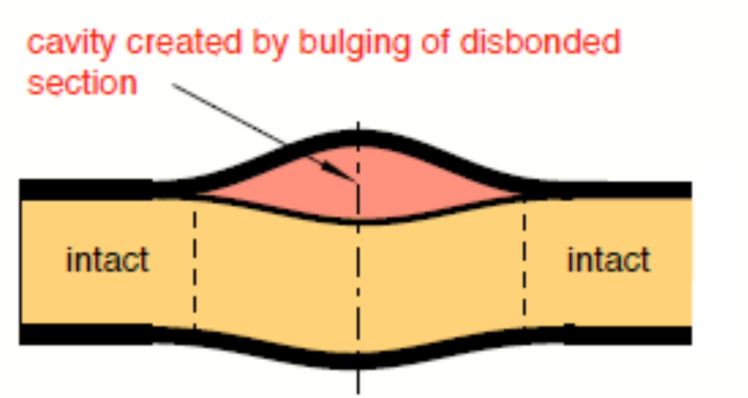
<u>Configuration at ground level</u>

P_o = 100 kPa = 14.7 psi



<u>Configuration at 35,000 ft</u>

P_o = 24 kPa = 3.5 psi



Effects of Moisture Diffusion in Sandwich Composites

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  - Water ingression into core, followed by freeze-thaw cycles
- Water ingression most commonly attributed to wicking of liquidous water through microcracks, along fiber/matrix interface, and/or through improper edge closeouts (all accentuated by GAG pressure cycles)
- Water ingression may also occur simply due to diffusion of water molecules through (undamaged) facesheets

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Effects of Moisture Diffusion in Sandwich Composites

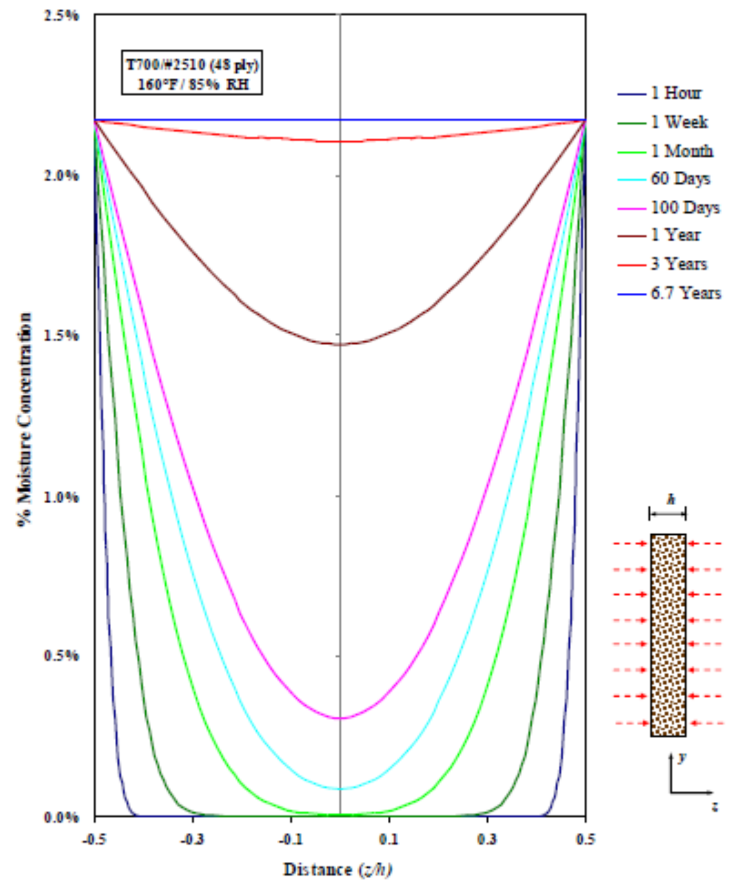
Motivation and Key Issues:

- Significant moisture transport via diffusion typically requires months or years, depending on:
  - Temperature
  - Thickness and material properties
  - External humidity level

Effects of Moisture Diffusion in Sandwich Composites

<u>Motivation and Key Issues</u>:

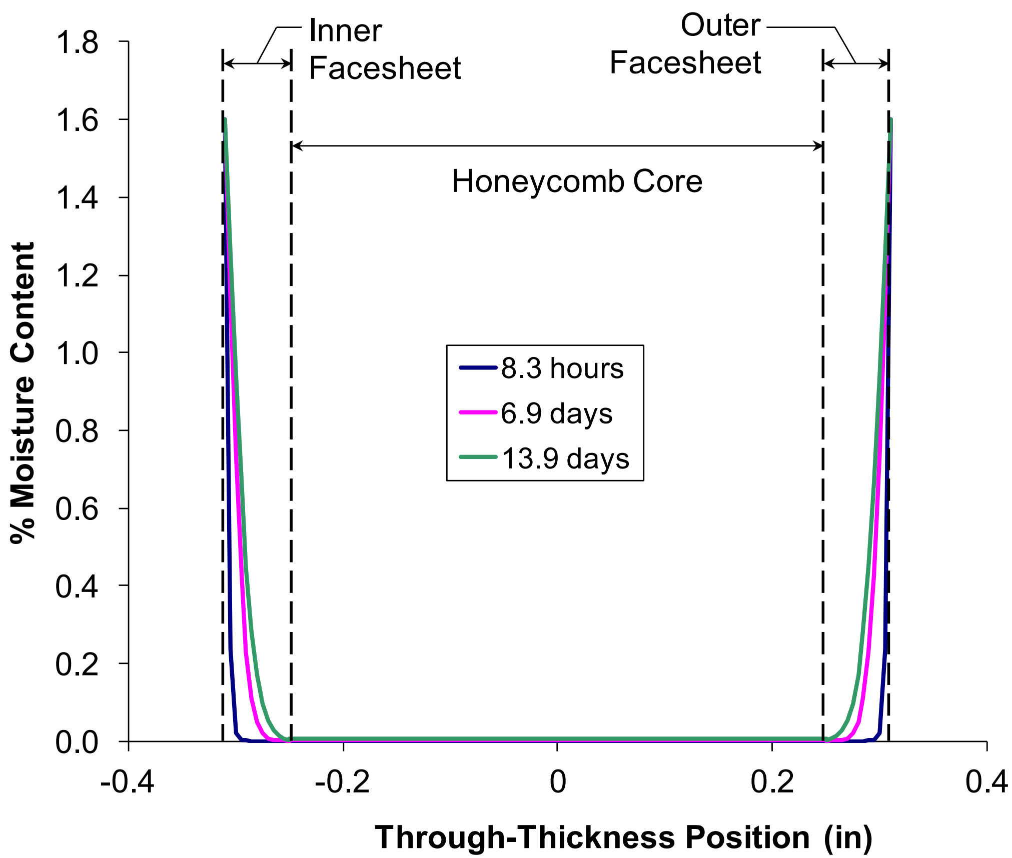
Moisture diffusion in solid 48-ply Gr-Ep laminate; 160ºF, 85%RH (W. Seneviratne and J. Tomblin, JAMS 2012)



Effects of Moisture Diffusion in Sandwich Composites

Motivation and Key Issues:

Moisture diffusion in honeycomb sandwich panels:
-12-ply Gr-Ep facesheets
- 0.5 in Nomex core
- 90ºF, 80%RH
(Tuttle, AMTAS 2009)



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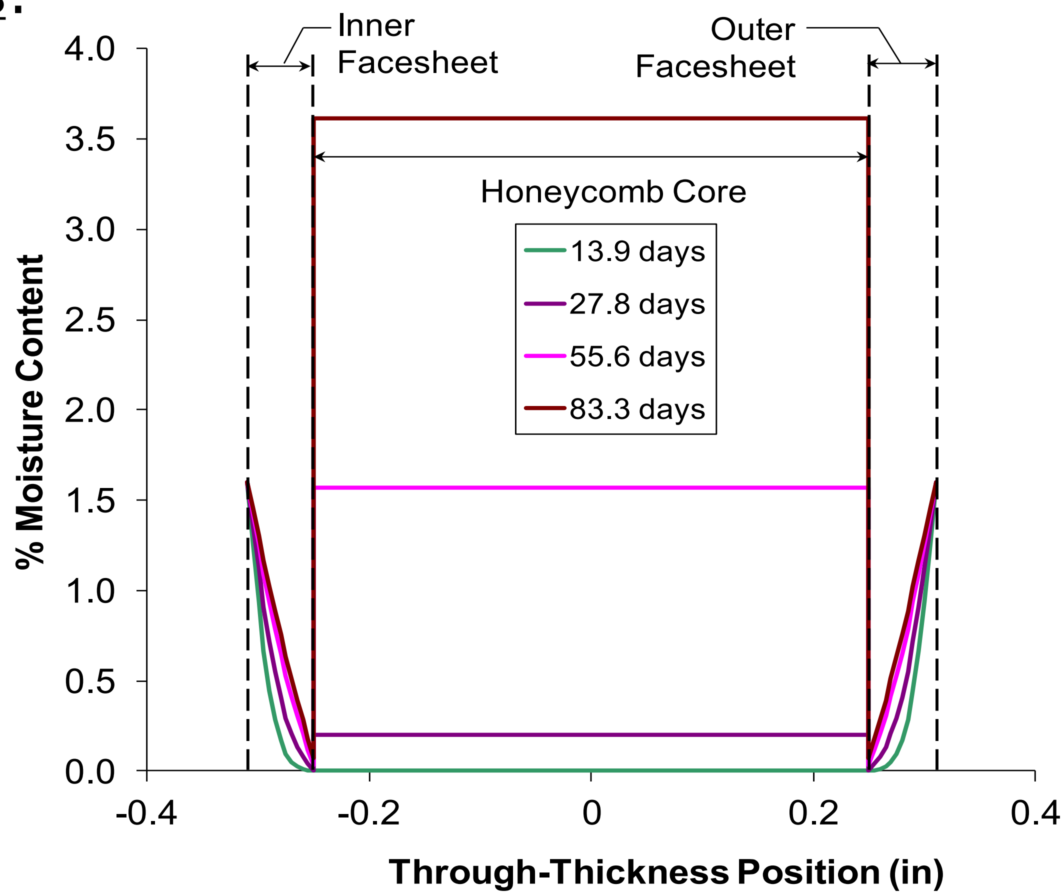

Effects of Moisture Diffusion in Sandwich Composites

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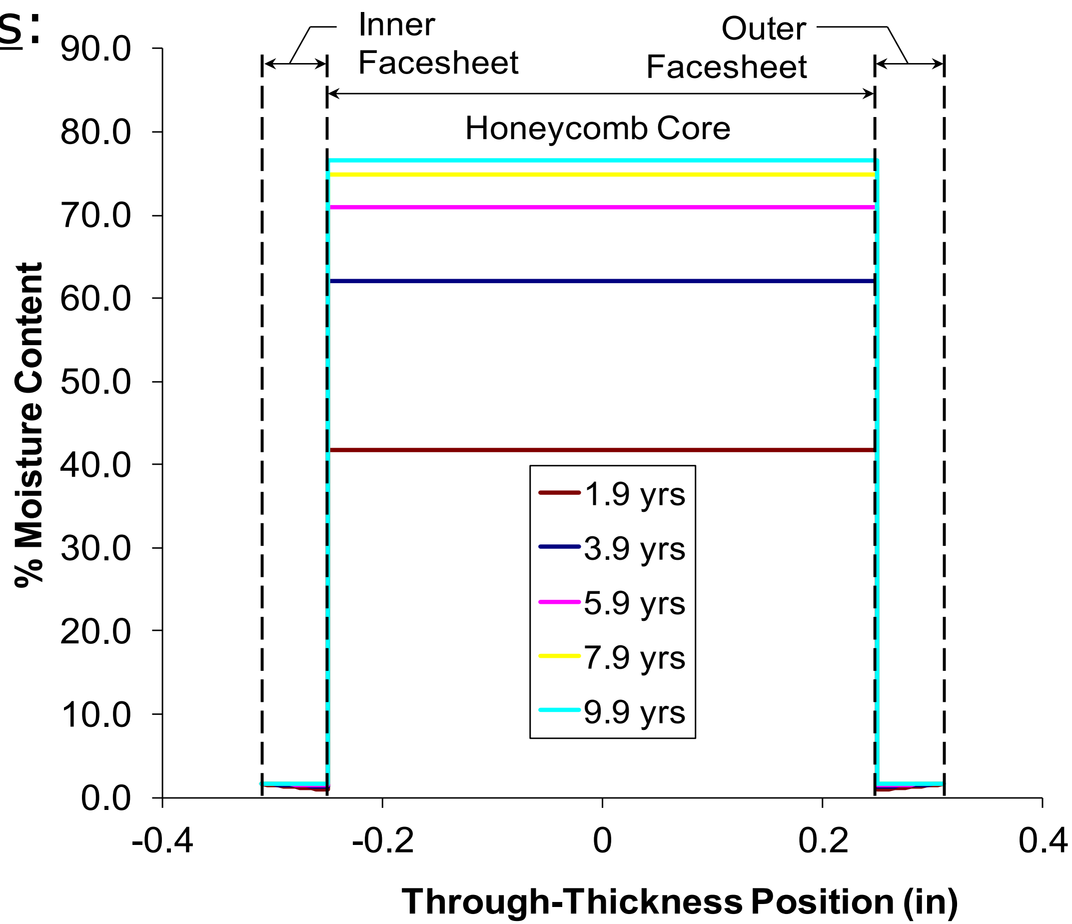

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Effects of Moisture Diffusion in Sandwich Composites

Implication:
Since sandwich structures are exposed to low external temperatures during flight (-50ºC), a condense-freeze-thaw-evaporate cycle will occur as internal humidity increases within the core volume of a sandwich composite, even if no mechanical damage of the facesheet has occurred

Objective of this study:
Determine if the condense-freeze-thaw-evaporate cycle is detrimental by monitoring room-temperature interfacial fracture toughness, G_c, associated with facesheet disbonding for four specimen types:

- Type A: As produced, "dry" specimens
- Type B: "Dry" specimens exposed to 300 thermal cycles from RT to -50ºC
- Type C: "Humid" specimens, with internal core humidity ~80%RH
- Type D: "Humid" specimens exposed to 700 thermal cycles from RT to -50ºC

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Effects of Moisture Diffusion in Sandwich Composites

- UW Principal Investigator and Researchers
  - Mark Tuttle (PI), Shuyu 'Frank' Xia (MSME), William Smoot (MSME), Sung Lin 'Jason' Tien (MSAA)
- FAA Technical Monitors
  - Lynn Pham, Zhi-Ming Chen
- Additional FAA Personnel Involved
  - Larry Ilcewicz, Curt Davies, Dave Westlund
- Industry Participation
  - Hamid Razi, Adam Sawicki, Bill Avery/The Boeing Company
  - Dan Holley and Chris Praggastis/3M
  - Bob Fagerlund/Bell Helicopter
- Study Initiated in September 2015

Effects of Moisture Diffusion in Sandwich Composites

Technical Approach

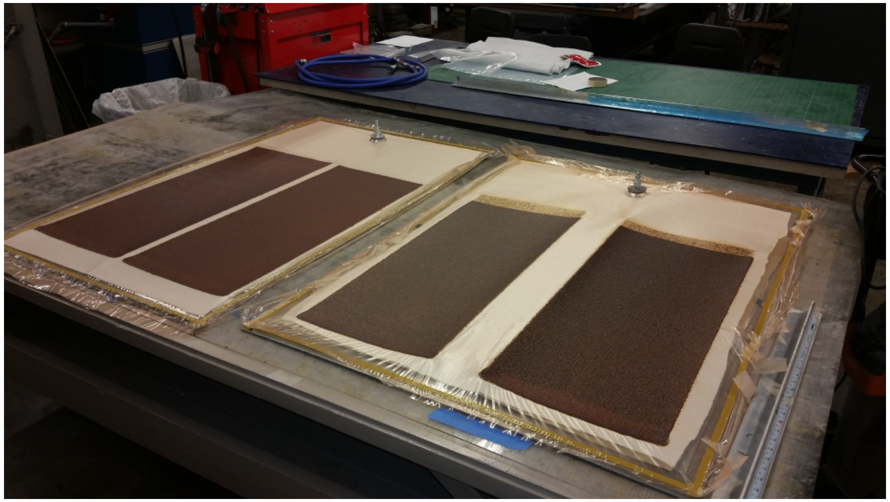
- Sandwich panels with 4-ply *woven* facesheets and $[45/0/0/45]_T$ stacking sequence:

Type	Manufacturer/Material Designation
Facesheet	Cytec T300/970 3k plain weave fabric
Core	Hexcel HRH-10 – 1/8 – 3.0 (0.50 in thick)
Adhesive	3M Scotch-Weld Structural Film AF 163-2K

Effects of Moisture Diffusion in Sandwich Composites

Technical Approach

- Facesheets produced using an autoclave:



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Effects of Moisture Diffusion in Sandwich Composites

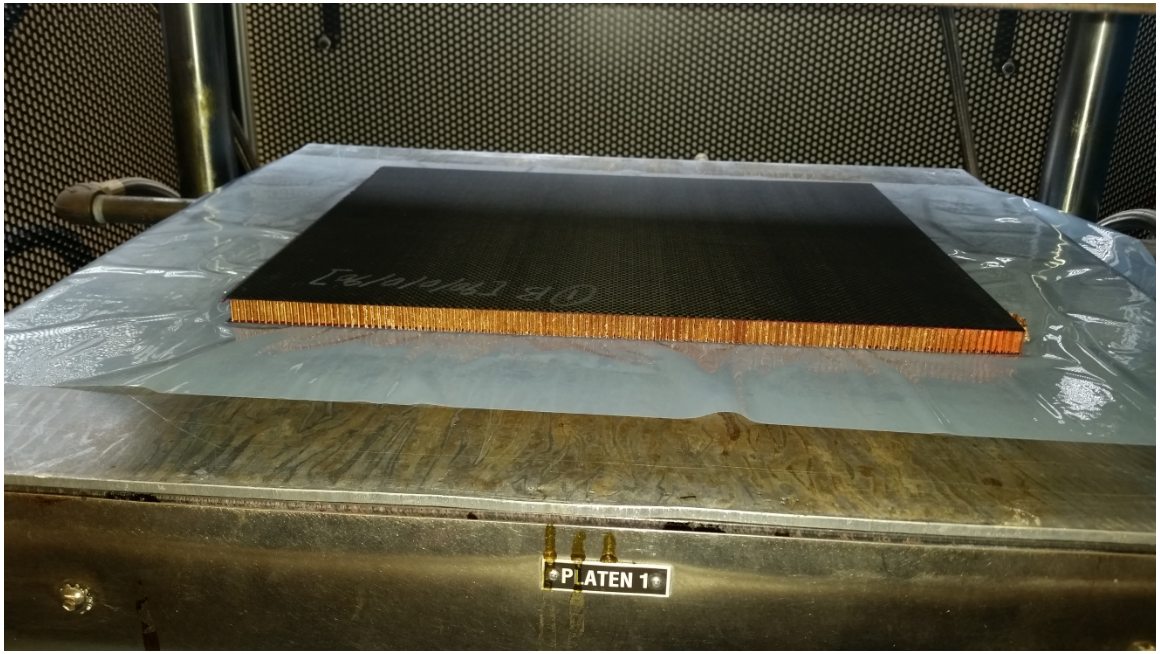
Technical Approach

- The cured facesheets and Nomex core were machined to size and stored for 2 months at 50ºC (122ºF) at 8% RH in a humidity chamber, to insure components were as “dry” as possible

Effects of Moisture Diffusion in Sandwich Composites

Technical Approach

- Four parent sandwich panels were then produced using dried facesheets and core, using secondary bonding and a hot press



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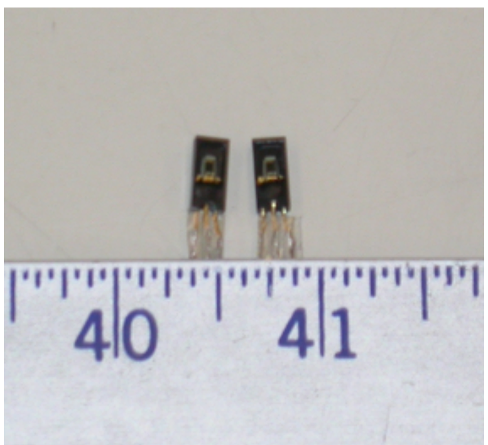
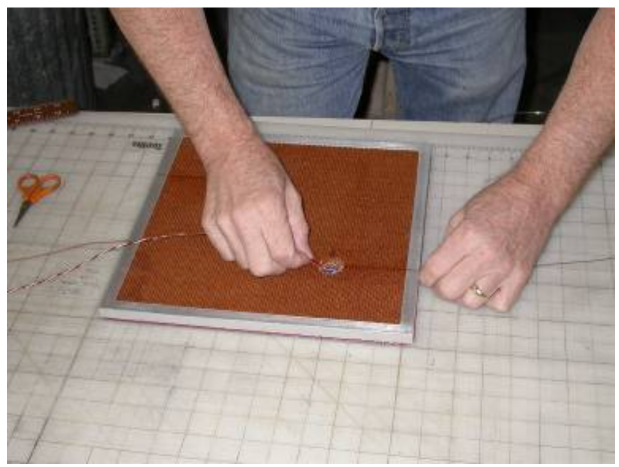
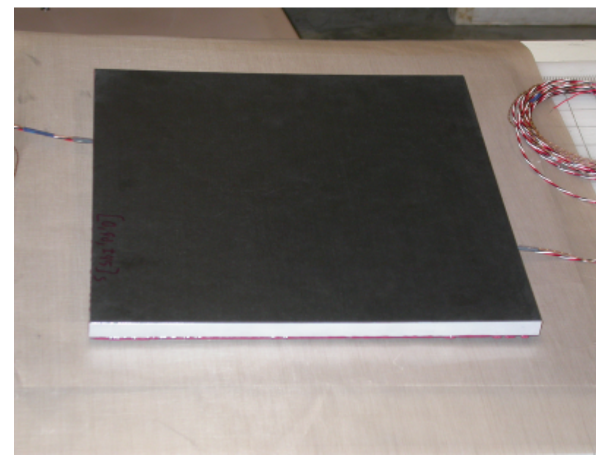
Effects of Moisture Diffusion in Sandwich Composites

Technical Approach

- Also fabricated instrumented “witness” panels with Ohmic Instruments Model HC-610 capacitive humidity sensors to monitor core humidity levels







Effects of Moisture Diffusion in Sandwich Composites

Technical Approach

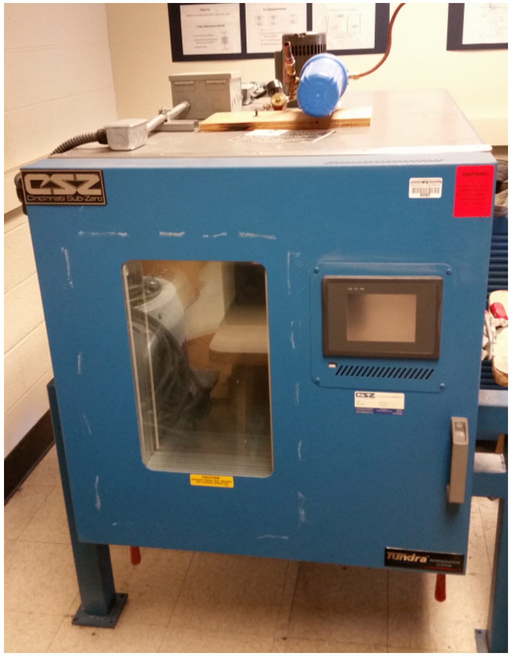
- Six tests specimens were machined from the four "parent" panels (24 test specimens in total)
- Specimens produced from each panel were used for each Type, to avoid any potential manufacturing bias

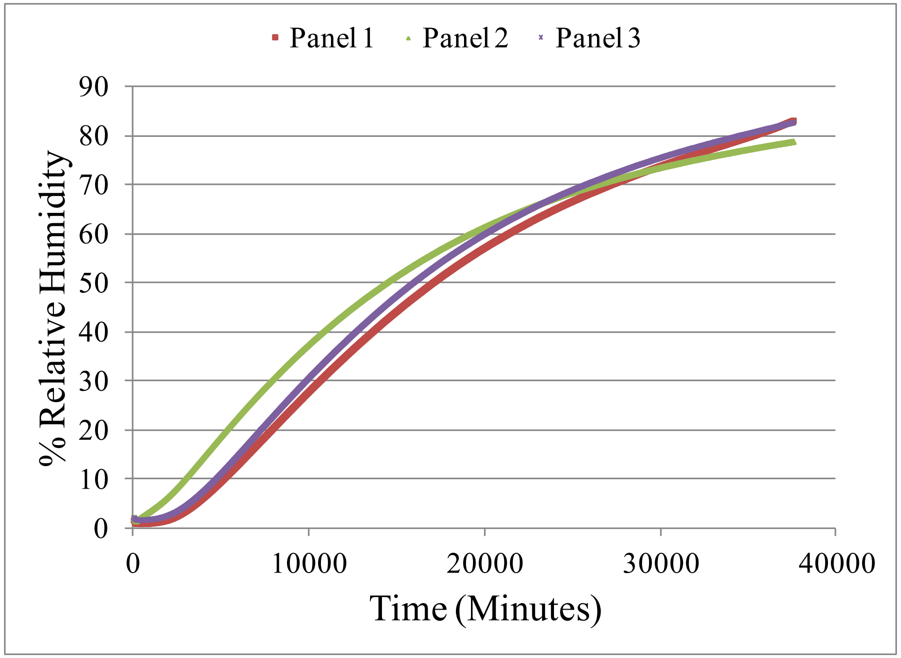
Type	Specimen Number					
A (as-produced)	1-1	2-2	3-3	4-4	1-5	2-6
B (thermally cycled)	2-1	3-2	4-3	1-4	2-5	3-6
C (humid)	3-1	4-2	1-3	2-4	3-5	4-6
D (humid&thermally Cycled)	4-1	1-2	2-3	3-4	4-5	1-6

Effects of Moisture Diffusion in Sandwich Composites

Technical Approach

- Three witness panels and all Type C and D specimens were placed in the humidity chamber at 65ºC (150ºF) and 90%RH. Core humidity levels increased to about 80% in one month

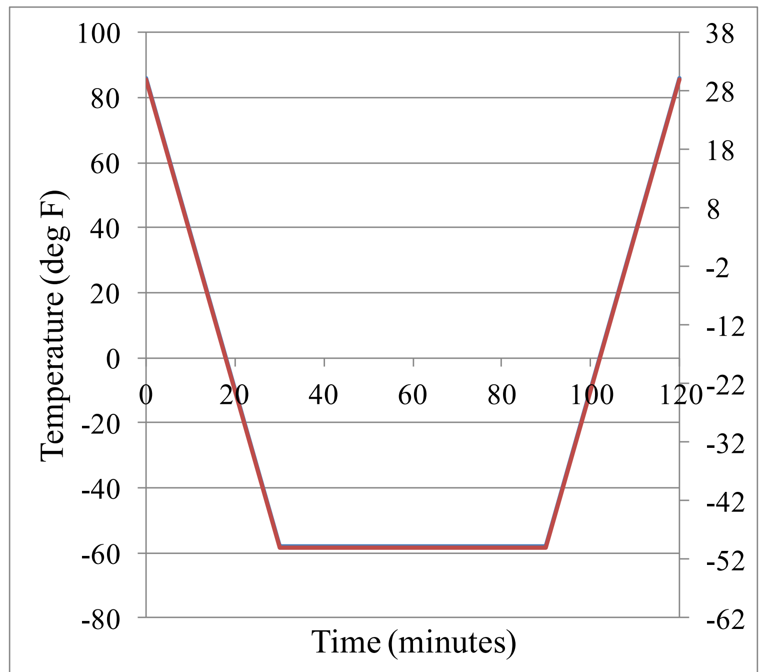




Effects of Moisture Diffusion in Sandwich Composites

Technical Approach

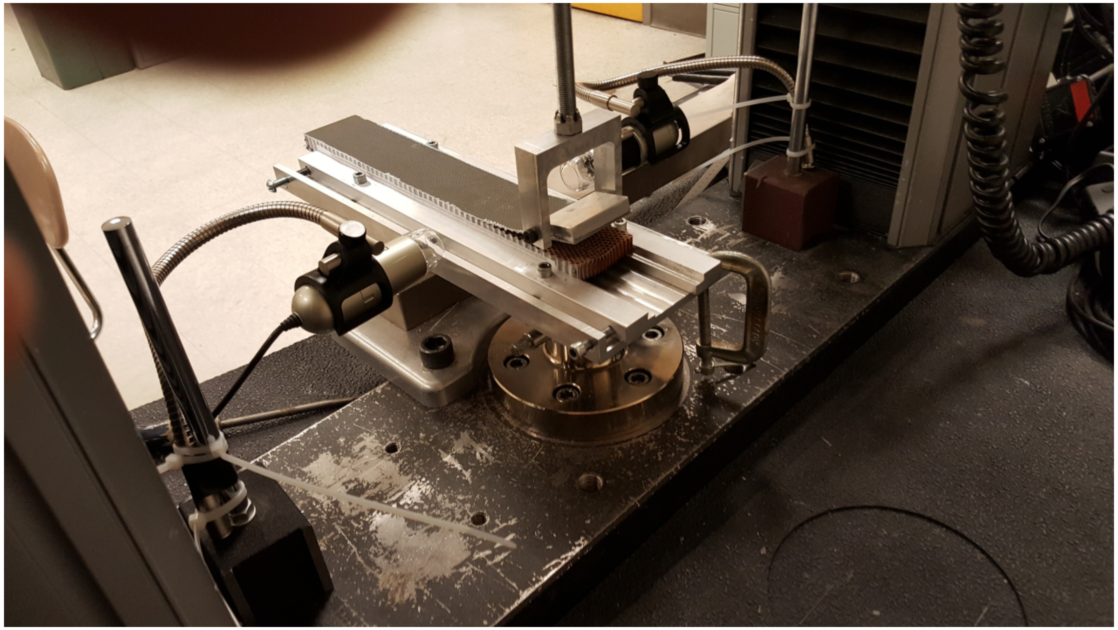
- All thermally-cycled specimens (Types B and D) were individually vacuum bagged (to insure constant moisture content in core volume) and subjected to 2-hr thermal cycles from 30ºC ↔ -50ºC



Effects of Moisture Diffusion in Sandwich Composites

Technical Approach

- The interfacial fracture toughness, G_c, was measured in accordance with a (draft) single-cantilever-beam (SCB) test standard being developed by Dan Adams, Waruna Seneviratne, and other members of a CMH-17 working group



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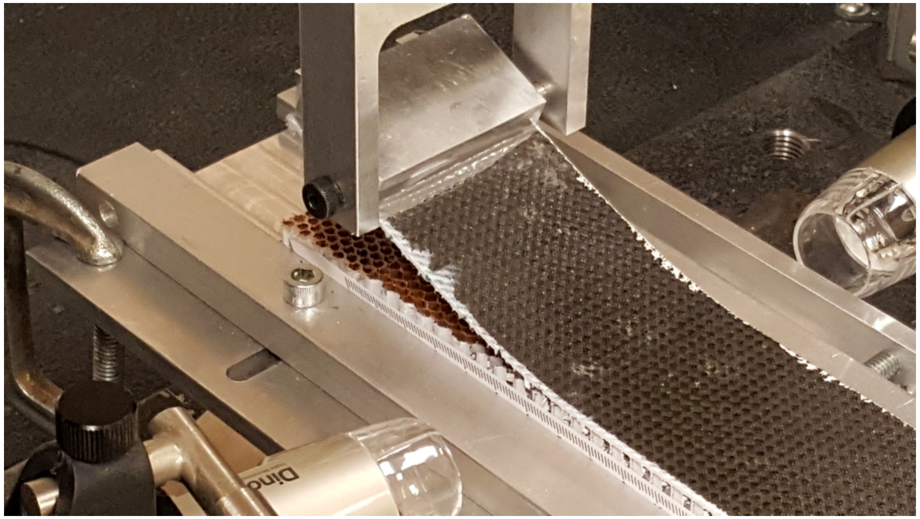
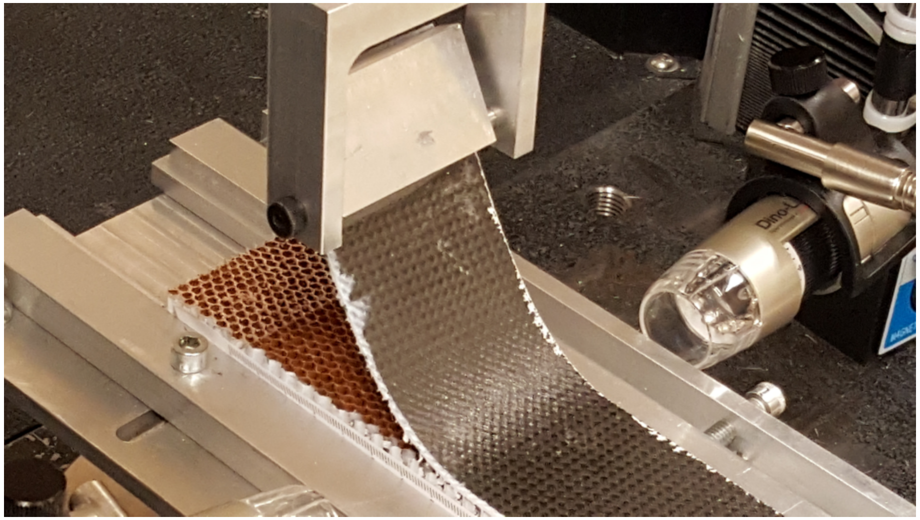
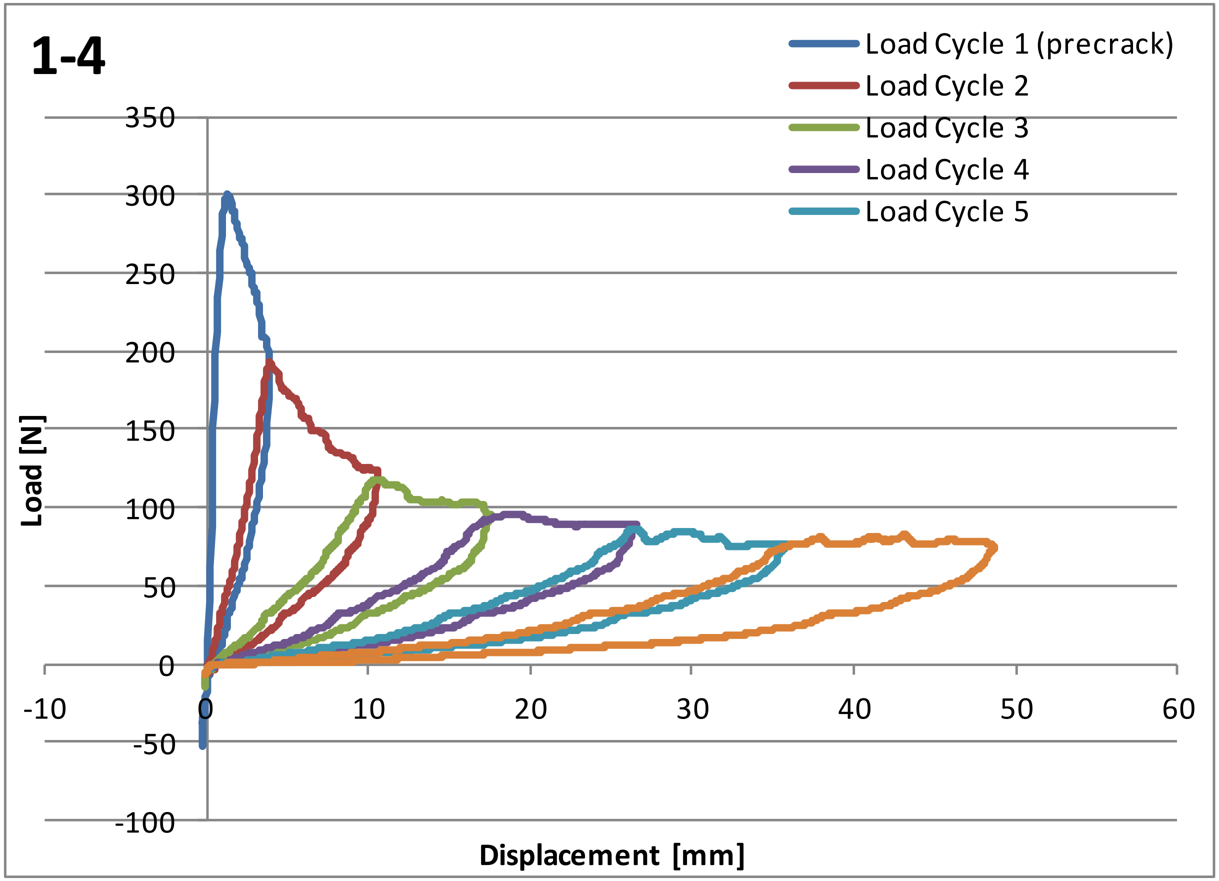




Effects of Moisture Diffusion in Sandwich Composites

Technical Approach

- A typical test involves six load cycles
- Crack length is measured after each cycle
- G_c can be calculated using data collected during any one of the six cycles (data from cycle 1 is normally discarded)



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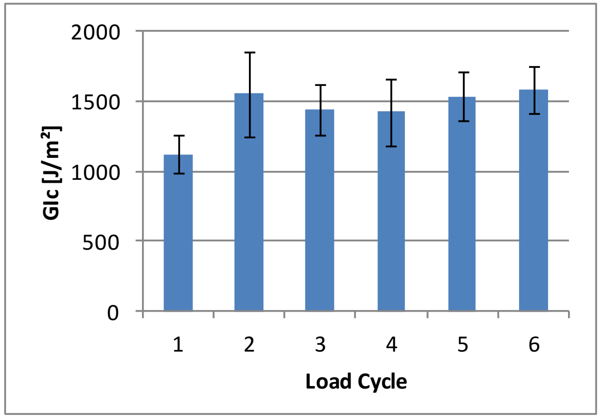
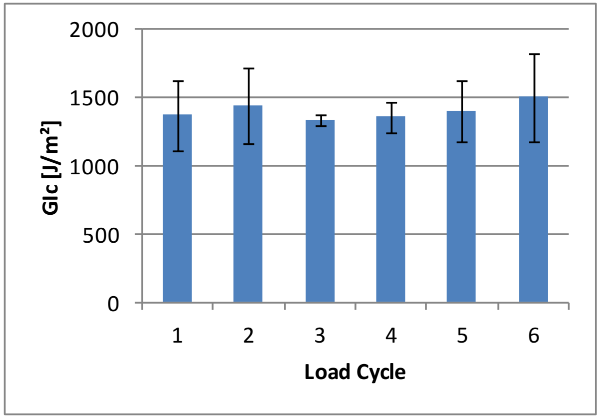
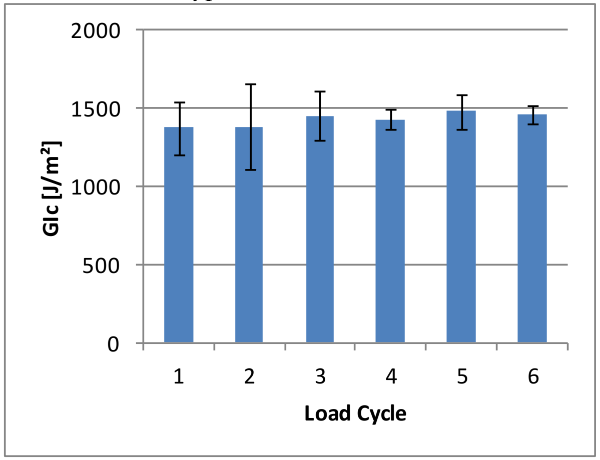


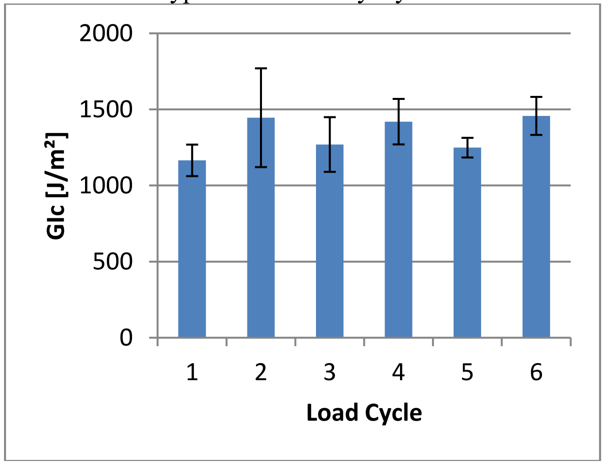
Type A – As Produced



Type B – Thermally Cycled



Type C - Humid



Type D – Humid and Thermally Cycled

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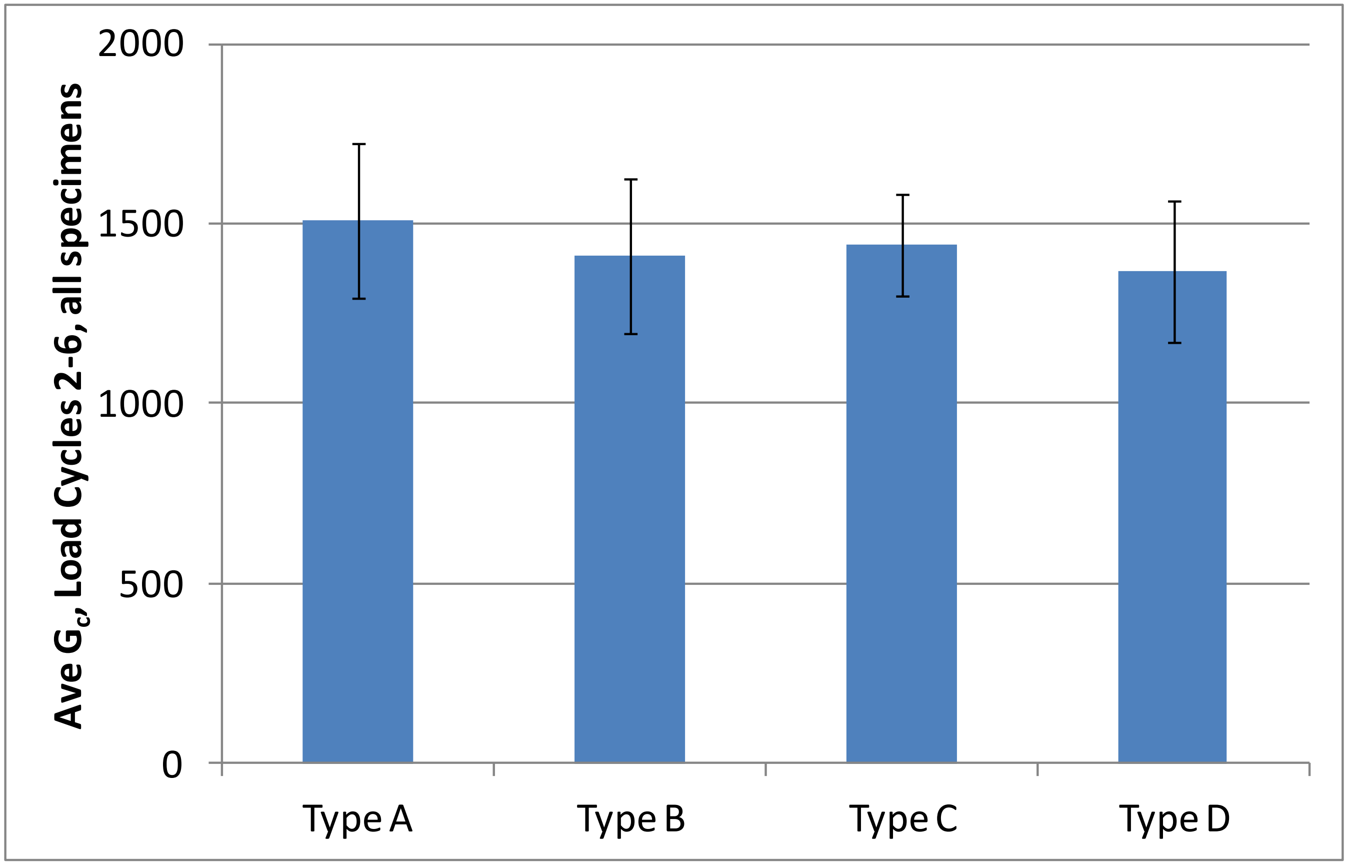

Effects of Moisture Diffusion in Sandwich Composites

Condition	Ave G_c (J/m^2)	StdDev G_c (J/m^2)	Average G_c, Normalized to Type A
Type A	1508	213	1.00
Type B	1410	214	0.94
Type C	1440	142	0.95
Type D	1368	198	0.91

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Effects of Moisture Diffusion in Sandwich Composites

Conclusions

- Environmental factors (i.e., thermal cycling and/or elevated humidity levels) have a modest but measureable impact on interfacial fracture toughness, G_c, associated with facesheet disbonding in sandwich composites

- The most aggressive environmental conditions considered during this study (humid specimens exposed to 700 thermal cycles from RT to -50ºC) resulted in about a 10% reduction in G_c.

Effects of Moisture Diffusion in Sandwich Composites

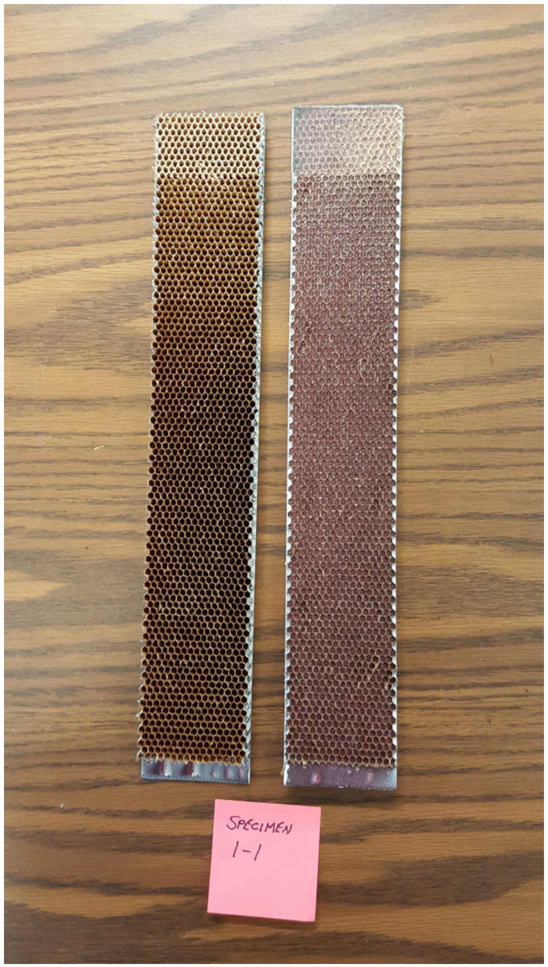
A Look Ahead

- Expand Test Matrix:
  - Kevlar honeycomb core
  - Different Nomex core densities (e.g., 8 lb/ft^3)
  - Thinner (3-ply?) and thicker (8-ply?) facesheets
- Formally participate in CMH-17 sandwich disbond round-robin study

Thank You!

Questions, Comments, Suggestions?

Backup Slides


SPECIMEN
1-1