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CENTER OF EXCELLENCE

Effects of Moisture Diffusion in Sandwich Composites

2017 Technical Review

Shuyu 'Frank' Xia , Hrishikesh (Rishi) Pathak, Anirudh Ashok, and Mark Tuttle

Department of Mechanical Engineering

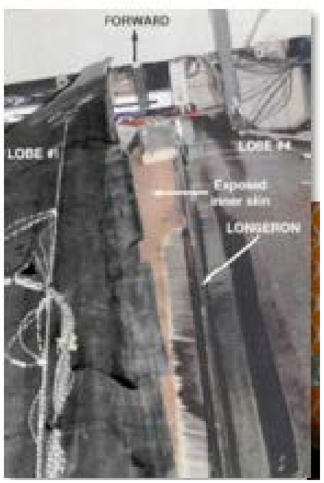
University of Washington

Effects of Moisture Diffusion in Sandwich Composites

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

• In-service bond failures between composite facesheets and honeycomb cores have been reported in the space, marine, and aviation industries

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

Motivation and Key Issues:

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    ….water ingression may occur due to:
    - Wicking of liquidous water through facesheet microcracks, along fiber/matrix interfaces, and/or through improper design of edge closeouts

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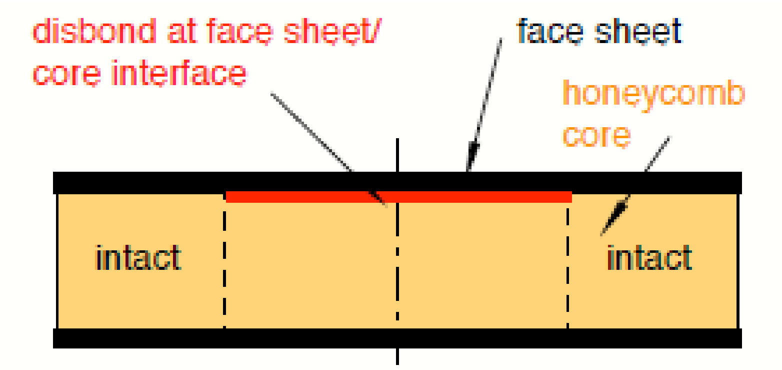
  - Pressure differences between inside and outside of unvented honeycomb cores (Ground-Air-Ground or 'GAG' pressure cycles)

Effects of Moisture Diffusion in Sandwich Composites

- Pressure differences between inside and outside of unvented honeycomb structures (Ground-Air-Ground or 'GAG' pressure cycles)

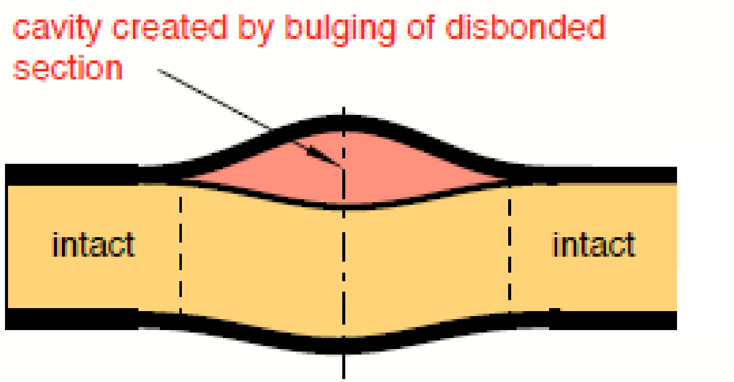
<u>Configuration at ground level</u>

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

Overall Program Objectives:

- Determine if the condense-freeze-thaw-evaporate cycle of humidity within core region impacts the interfacial fracture toughness, G_c, of sandwich structures

- Develop experimental techniques to study/evaluate GAG phenomenon

Effects of Moisture Diffusion in Sandwich Composites

- **Principal Investigator**
    - Mark Tuttle

- **Students**
    - William Smoot (MSME Aug ‘16), Sung Lin ‘Jason’ Tien (MSAA Sept ‘16), Shuyu ‘Frank’ Xia (MSME March ‘17), Hrishikesh (Rishi) Pathak, and Anirudh Ashok

- **FAA Technical Monitor**
    - Lynn Pham, Zhi-Ming Chen

- **Industry Participation**
    - Bill Avery, Hamid Razi, and Adam Sawicki/The Boeing Company
    - Dan Holley and Chris Praggastis/3M
    - Bob Fagerlund/Bell Helicopter

- **Study Initiated in September 2015**

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Effects of Moisture Diffusion in Sandwich Composites

Outline of Presentation

- Measurement of G_c associated with facesheet/core bond failures in sandwich structures:
  - Single-Cantilever Beam (SCB) test geometry/protocol under development by CMH-17 Task Group
  - Results obtained during 1st year of study (Sept '15-Sept '16)

  } Presented at Oct '16 AMTAS meeting

  - Expanded test matrix for 2nd year of study (ongoing)
- Design and fabrication of GAG specimens and test set-up (ongoing)

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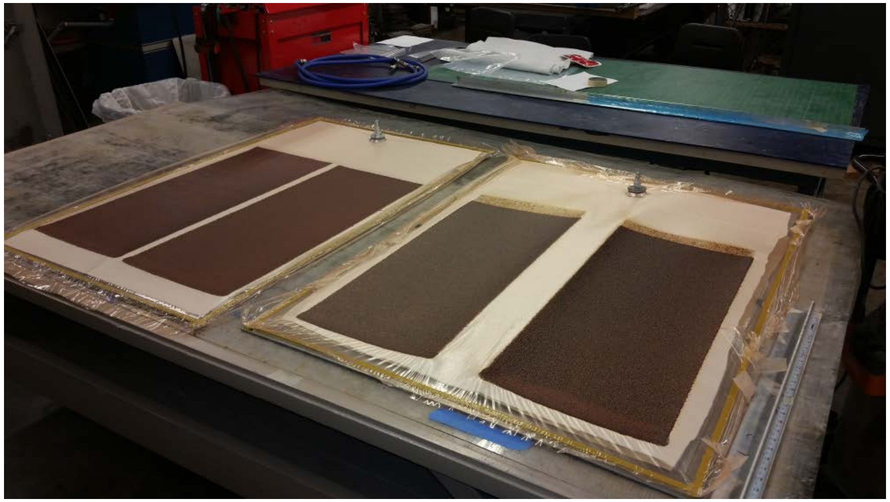
SCB Tests Conducted During 1st Year of Study

SCB specimens were machined from sandwich panels produced using 4-ply woven facesheets with $[45/0/0/45]_T$ stacking sequence and ½ in thick Nomex core:

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

SCB Tests Conducted During 1st Year of Study

Facesheets produced using an autoclave:



SCB Tests Conducted During 1st Year of Study

- 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

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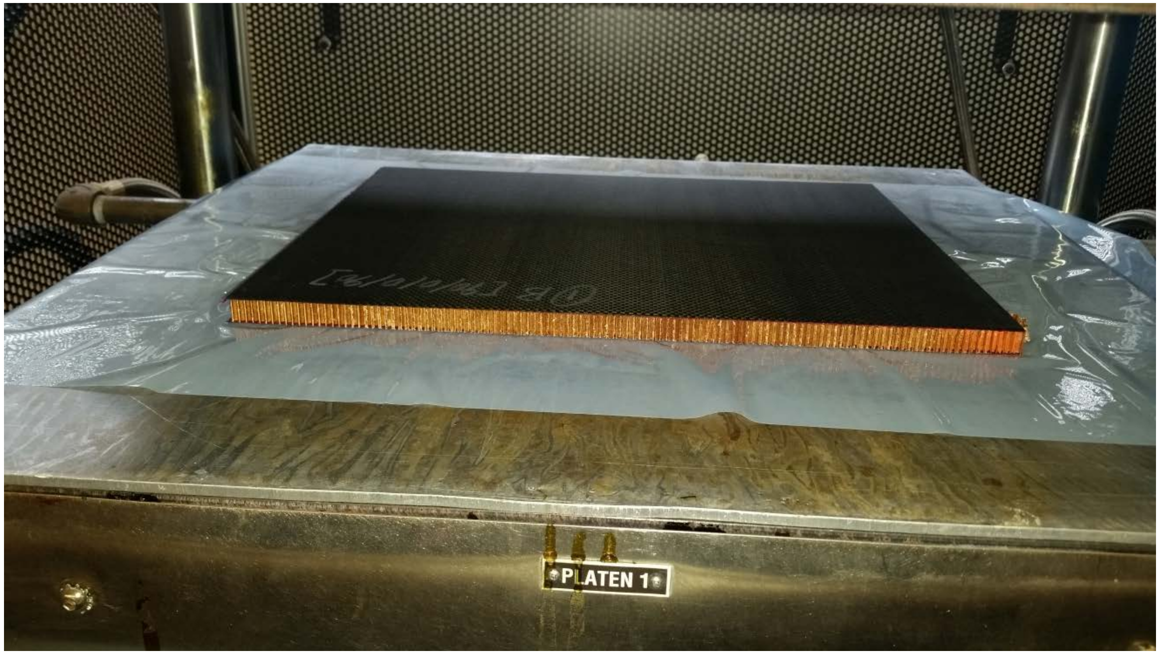
SCB Tests Conducted During 1st Year of Study

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



SCB Tests Conducted During 1st Year of Study

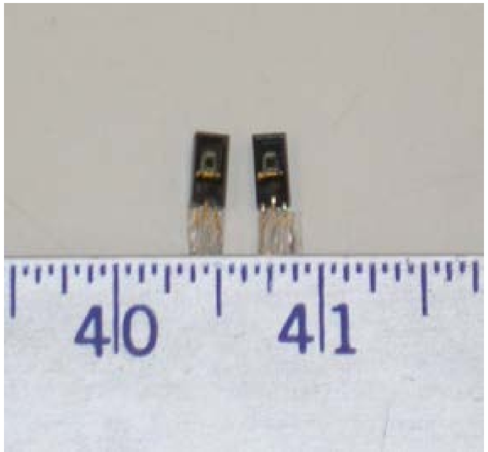
•Six tests specimens were machined from the four “parent” panels (24 test specimens in total)

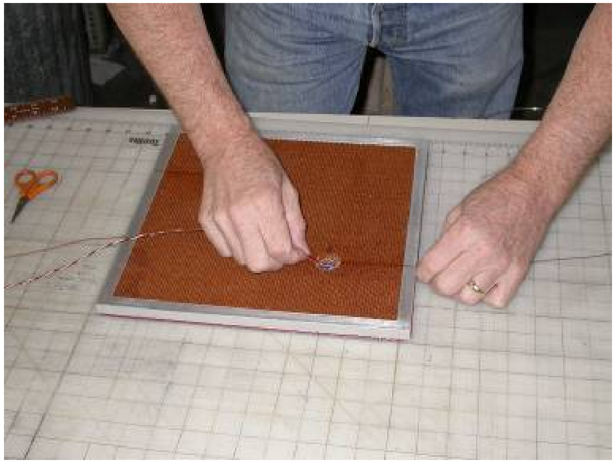
•Specimens produced from each panel were used for each Type, to avoid any potential manufacturing bias

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

SCB Tests Conducted During 1st Year of Study

•"Witness" panels were also fabricated. They were instrumented with Ohmic Instruments Model HC-610 capacitive humidity sensors to monitor core humidity levels





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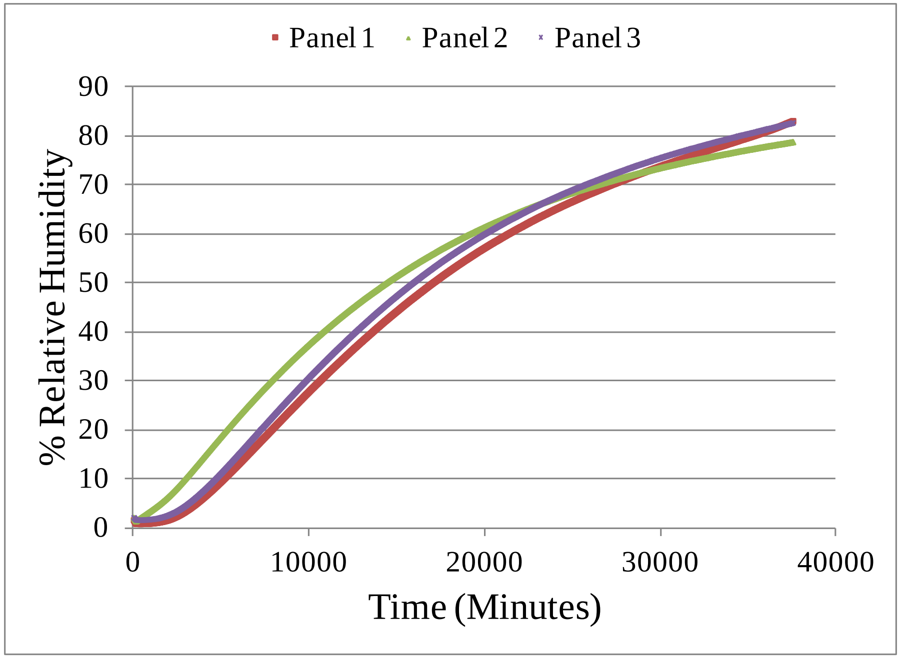
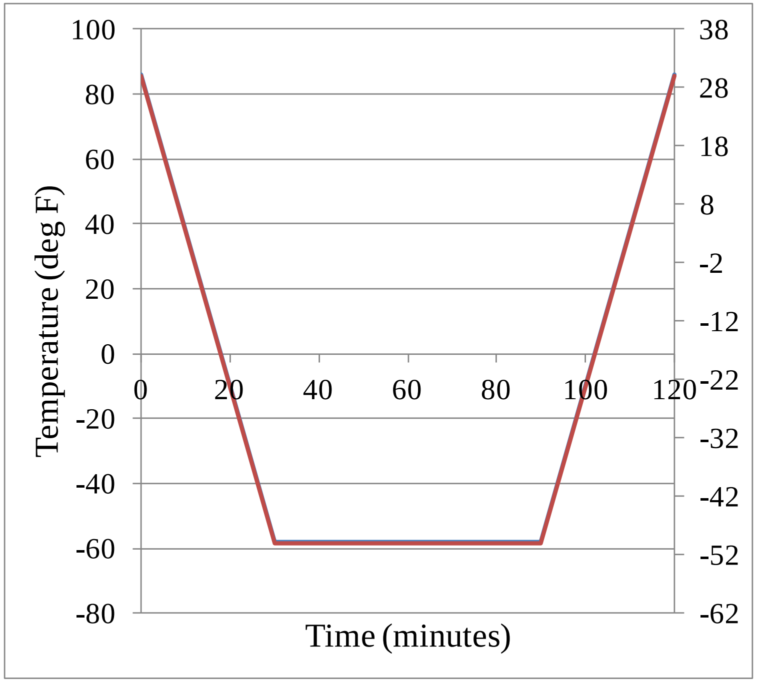
SCB Tests Conducted During 1st Year of Study

- 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



SCB Tests Conducted During 1st Year of Study

•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



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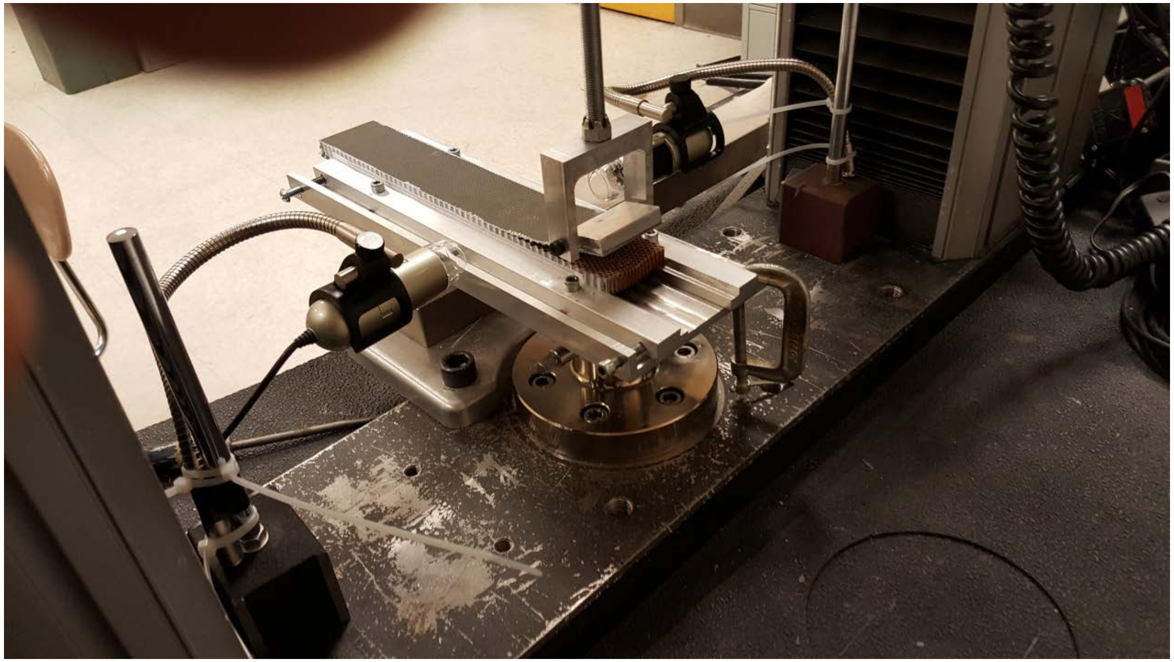
SCB Tests Conducted During 1st Year of Study

- The interfacial fracture toughness, G_c, was measured in accordance with the single-cantilever-beam (SCB) test standard being developed by a CMH-17 working group



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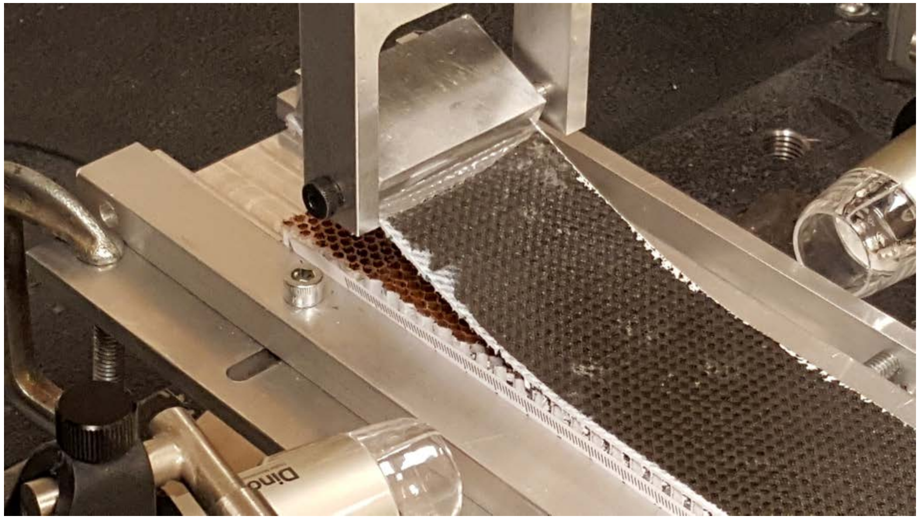
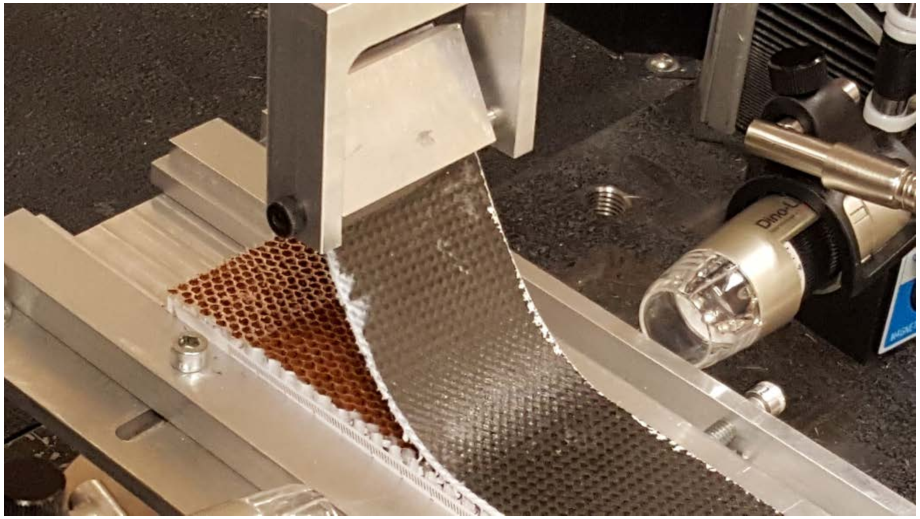


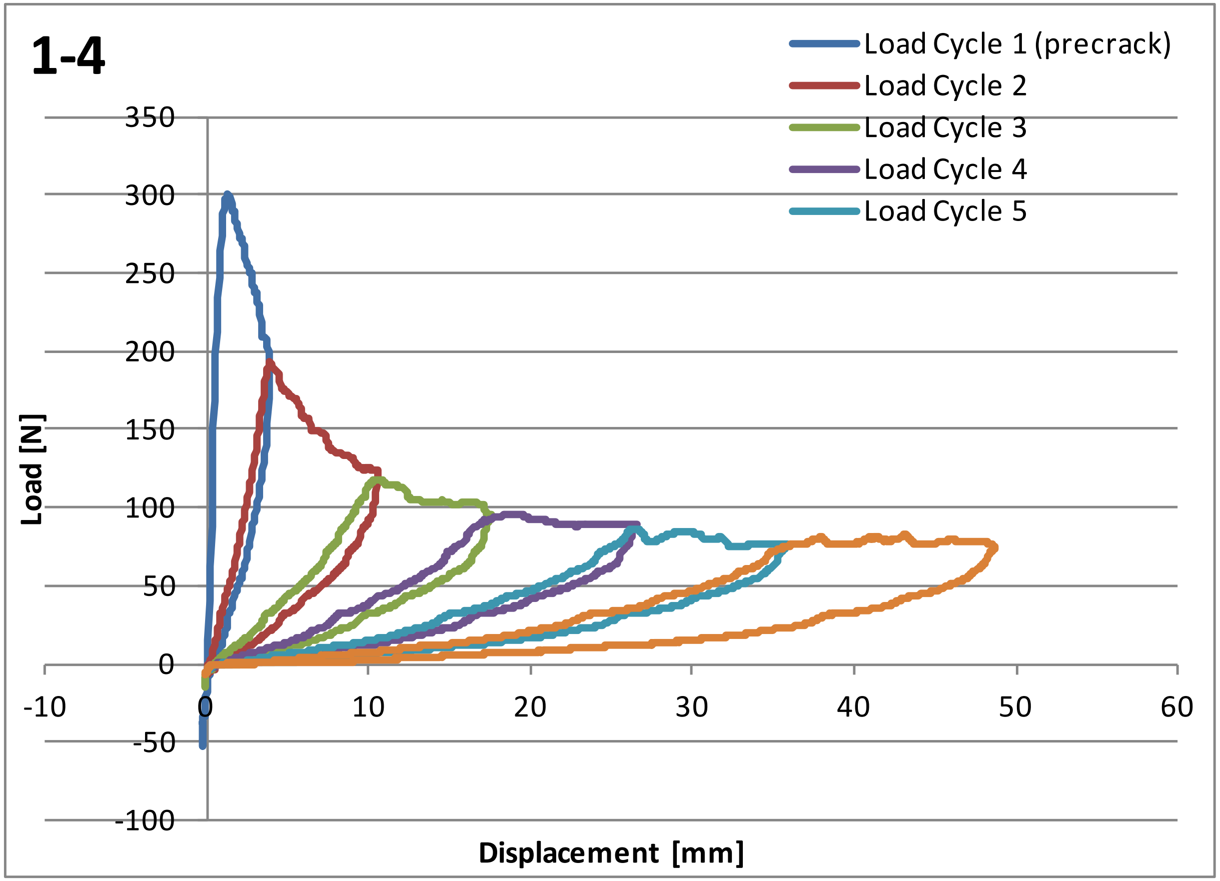


SCB Tests Conducted During 1st Year of Study

- A typical SCB 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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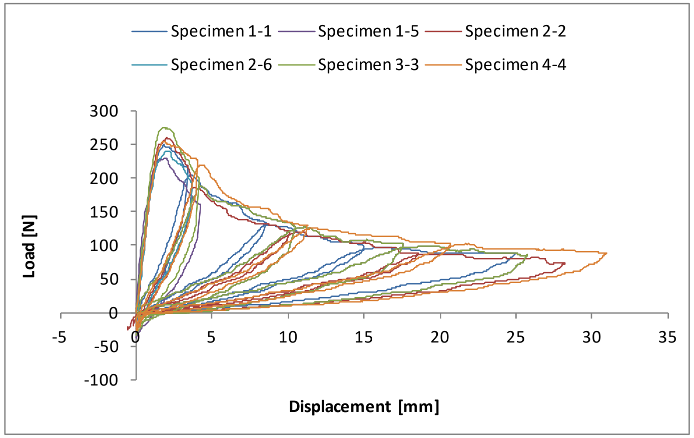
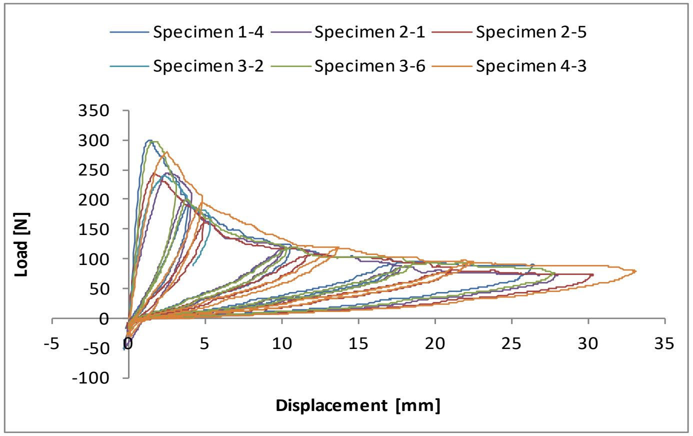
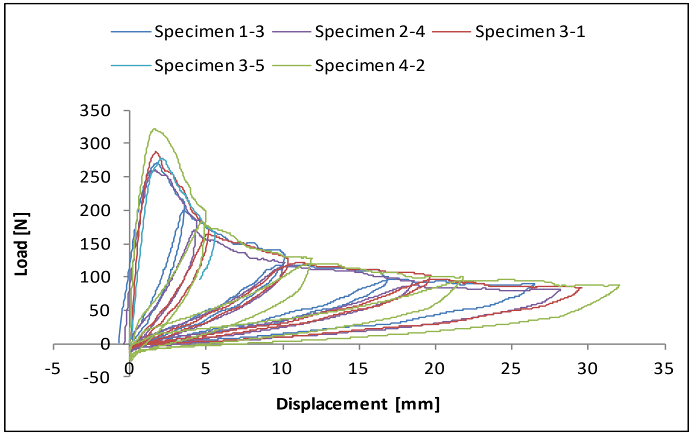


Type A – As Produced

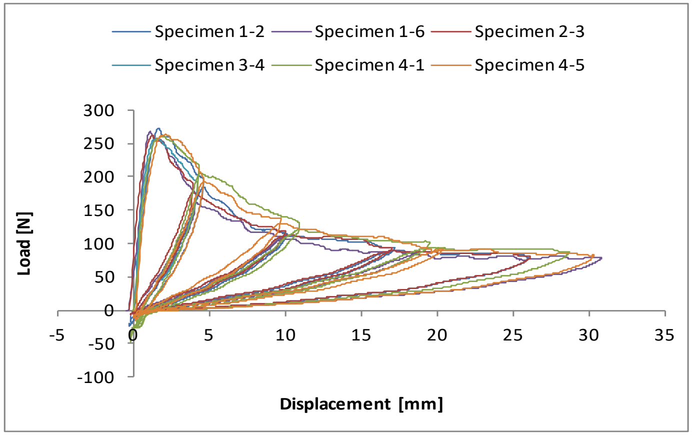


Type B – Thermally Cycled

One Type C Specimen Damaged Due to Equipment Malfunction



Type C– Humid



Type D– Humid & Thermally Cycled

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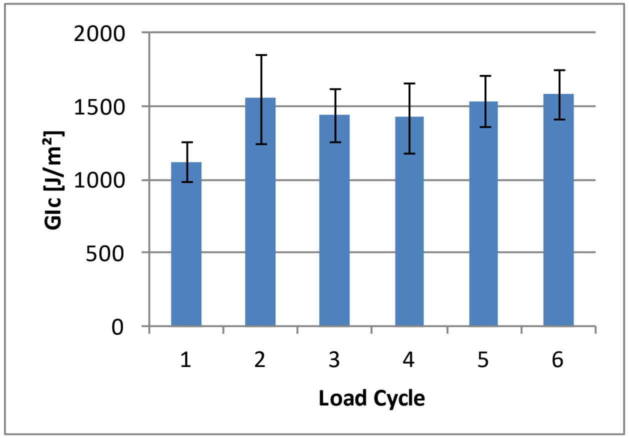
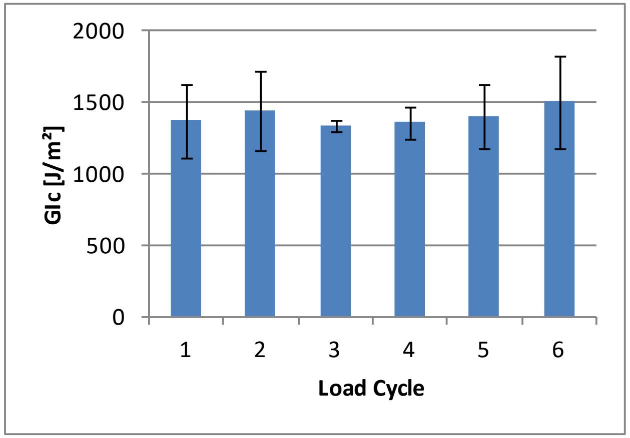
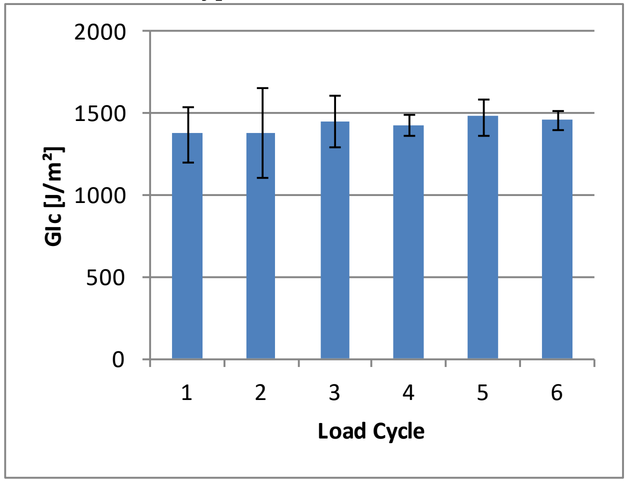
SCB Tests Conducted During 1st Year of Study



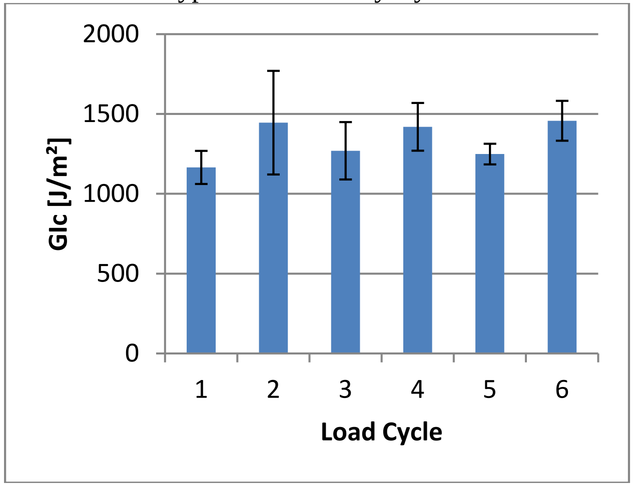
Type A – As Produced



Type B – Thermally Cycled

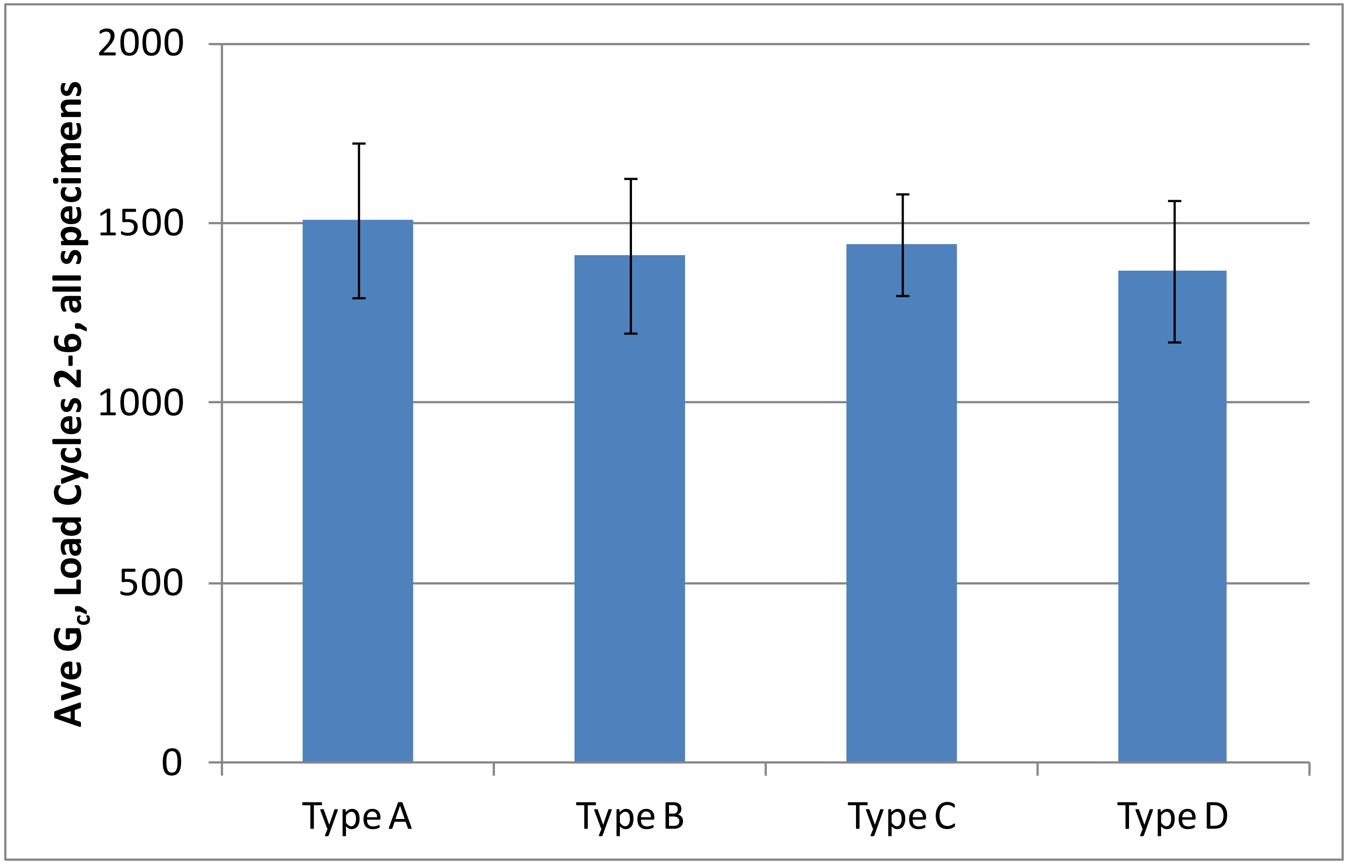


Type C - Humid



Type D – Humid and Thermally Cycled

SCB Tests Conducted During 1st Year of Study



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SCB Tests Conducted During 1st Year of Study

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

SCB Tests Conducted During 1st Year of Study

Preliminary Conclusions

- Although significant scatter was evident, it appears that environmental factors (i.e., thermal cycling and/or elevated humidity levels) have a modest but measureable impact on interfacial fracture toughness, G_c,

- 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 average G_c.

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Presented at Oct '16 AMTAS meeting

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SCB Tests Planned for 2nd Year of Study

Expanded Test Matrix:

Component	Description
Facesheet	Cytec T300/970 3k Plain Weave Fabric:
	$[45/0/0/45]_T$
	$[0/90/90/0]_T$
	$[0/45/0]_T$
	$[0/45/90/45]_s$
Core Materials	Hexcel HRH-10-1/8-3.0 (0.50 in thick)
	Hexcel HRH-10-1/8-3.0 (1.00 in thick)
	Hexcel HRH-10-1/8-8.0 (0.50 in thick)
	Hexcel HRH-36-1/8-3.0 (0.50 in thick)
Adhesive	3M Scotch-Weld Structural Film AF 163-2K

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Adhesive	3M Scotch-Weld Structural Film AF 163-2K

- Core materials recently received
- Test conditioning will be limited to "as produced" and "humid + thermally cycled"
- 18 "parent" panels being prepared (108 SCB specimens)

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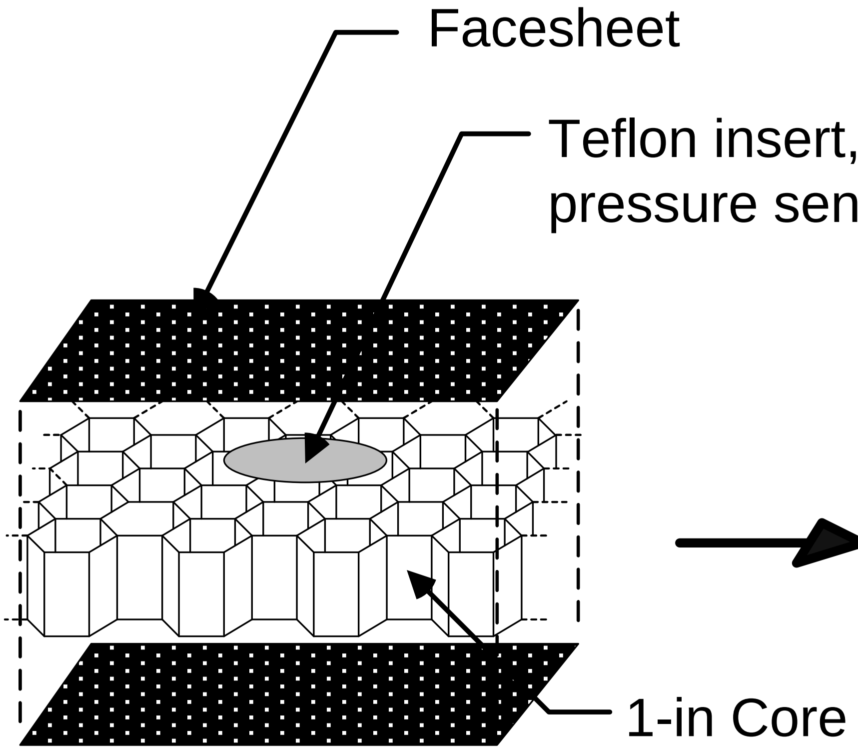
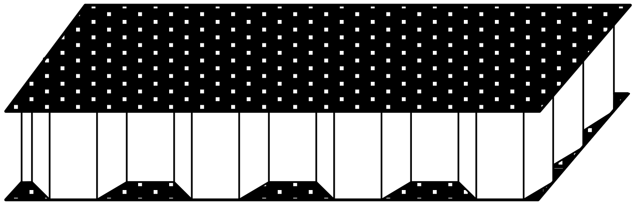
Design and Fabrication of GAG Specimen and Test Setup

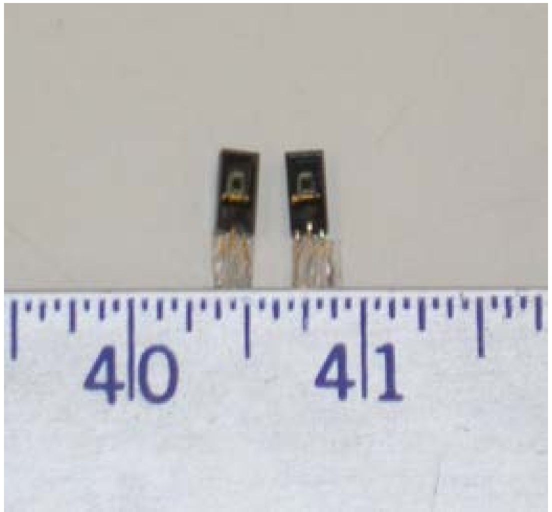
GAG Specimen:





Design and Fabrication of GAG Specimen and Test Setup

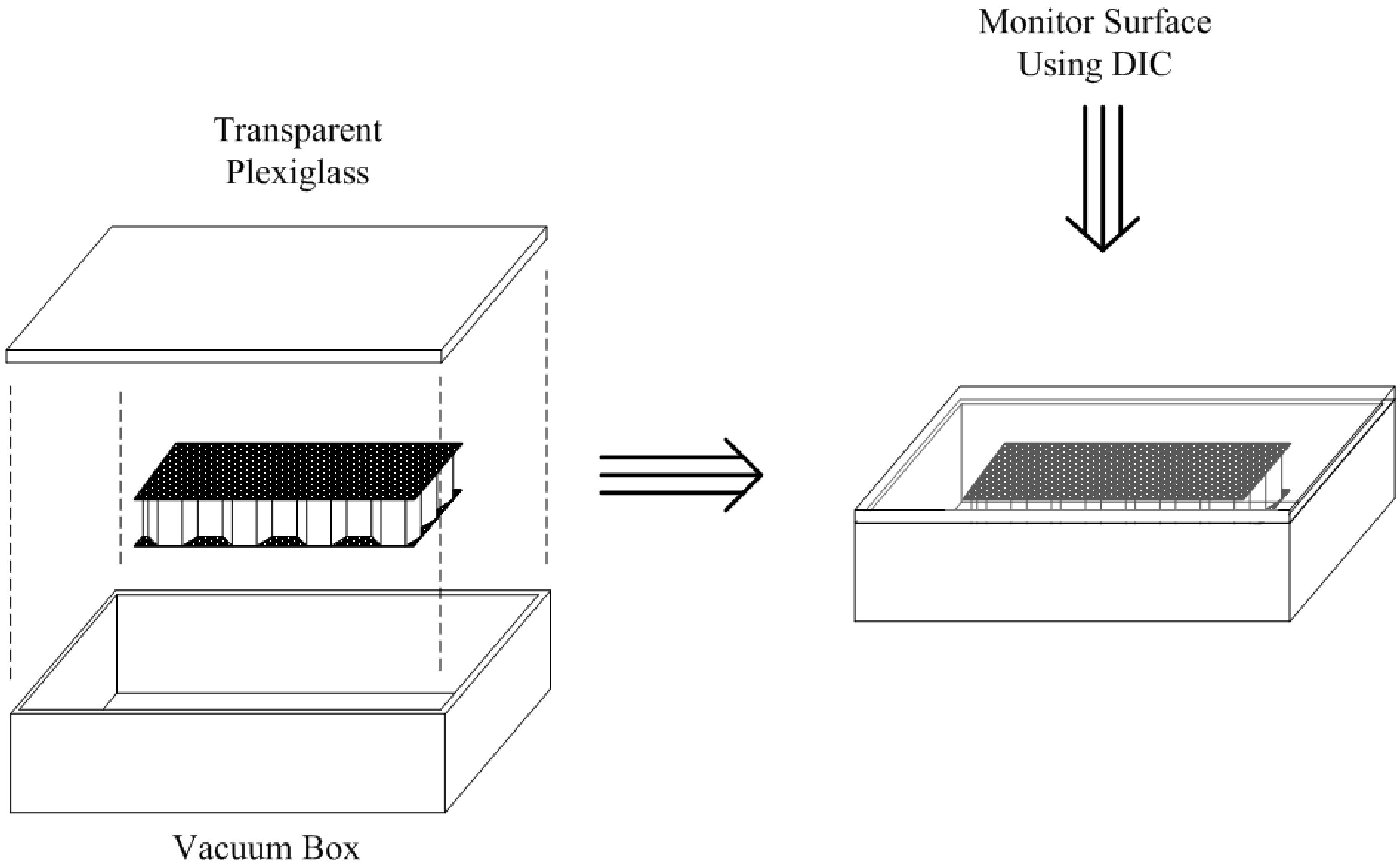
GAG specimens must use 1-in core, due to size of commercially-available pressure sensors



Ohmic Instruments Model HC-610 capacitive humidity sensors
Range = 5-95 %RH

All Sensors Type MLV-015A-A6-AAF-N pressure sensor with
0-15 psi pressure range (absolute)

Design and Fabrication of GAG Specimen and Test Setup



Design and Fabrication of GAG Specimen and Test Setup

Vacuum Box
Nearing Completion

Effects of Moisture Diffusion in Sandwich Composites

Benefit to Aviation:

Results of the study:

- Will clarify mechanisms 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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