Face Sheet/Core Disbonding in Sandwich Composite Components:
A Road Map to Standardization: *Test Method Development*

James Ratcliffe

NASA Langley Research Center, Hampton, Virginia

Ronald Krueger

National Institute of Aerospace, Hampton, Virginia

11th International Conference on Sandwich Structures

March 21-23, 2016

Collaborations

NASA
Ronald Krueger (NIA)
James Ratcliffe

University Partners
Daniel Adams – University of Utah
Waruna Seneviratne – NIAR/Wichita State

US Government Agencies
Larry Ilcewicz – FAA
Curt Davies – FAA
Zhi-Ming Chen – FAA

Supporting Projects
NASA Advanced Composites Project

Professional Societies
ASTM Committee D30 on Composite Materials
Composite Materials Handbook - CMH-17

Other Partners
Ley Richardson – DuPont, Richmond, VA
Yannick Albertone – DuPont, Switzerland
Ralf Hilgers – Airbus Hamburg, Germany
Christian Berggreen – DTU, Denmark
Martin Rinker - Fraunhofer Institute (FhG), Germany

Overview

- Background
- Road Map
- Development of a test method for fracture toughness testing
- Draft ASTM test method
- Round Robin Exercise
- Closing Remarks

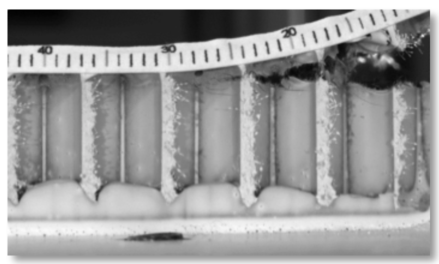
Background

- **Problem**
  - **In-service component failures associated with face sheet/core disbonding in unvented honeycomb core sandwich**
  - **Degradation due to disbonding affects operational safety**
  - **Failures may discourage use of composites in ‘future’ vehicles**
  - **Methods for assessing propensity of sandwich structures to disbonding not fully matured, accepted and documented**
  - **Methods development is currently being discussed within the Disbond/ Delamination Task Group in CMH-17**

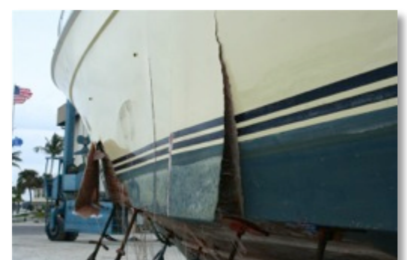
Space (X-33)

Detail of flaw

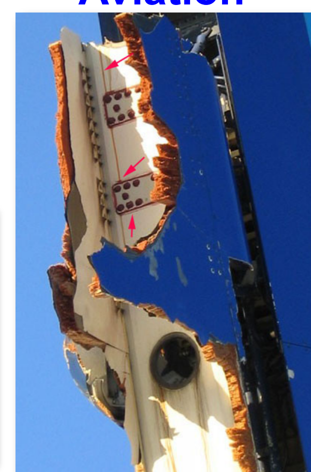
Face sheet/core disbonding*



Marine



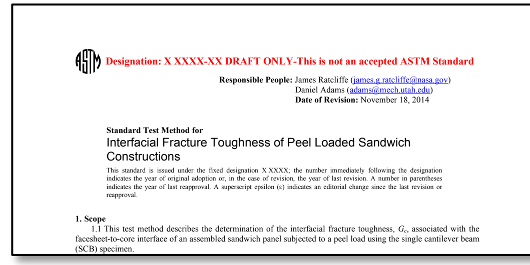
Aviation*



*Focus of this presentation

Road Map

- Ongoing CMH-17/ASTM D30 activity initiated 2012
- Current FAA initiative on Continuous Operational Safety (COS)
- **Objective**
  - Develop a fracture mechanics based methodology for damage tolerance assessment of sandwich structure
  - Assessment of face sheet/core disbonding in sandwich components similar to delamination in composite laminates
- **Approach**
  - Coupon test standard development
    - Test method for peel-dominated (mode I) interfacial fracture toughness*
    - Test method for mode II and mixed-mode interfacial fracture toughness
  - Analysis development
  - Panel testing for analysis validation
  - Publication
    - ASTM D30 fracture toughness standards¶
    - CMH-17 Vol. 6 best practices, guidelines and case studies



Designation: X XXXX-XX DRAFT ONLY-This is not an accepted ASTM Standard

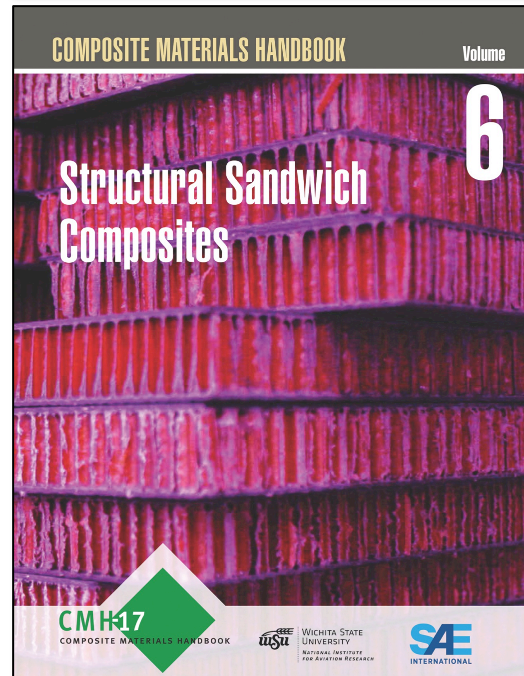
Responsible People: James Ratcliffe (james.g.ratcliffe@nasa.gov)
Daniel Adams (adams@mech.utah.edu)
Date of Revision: November 18, 2014

Standard Test Method for
Interfacial Fracture Toughness of Peel Loaded Sandwich Constructions

This standard is issued under the fixed designation X XXXX; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method describes the determination of the interfacial fracture toughness, G_c, associated with the facesheet-to-core interface of an assembled sandwich panel subjected to a peel load using the single cantilever beam (SCB) specimen.

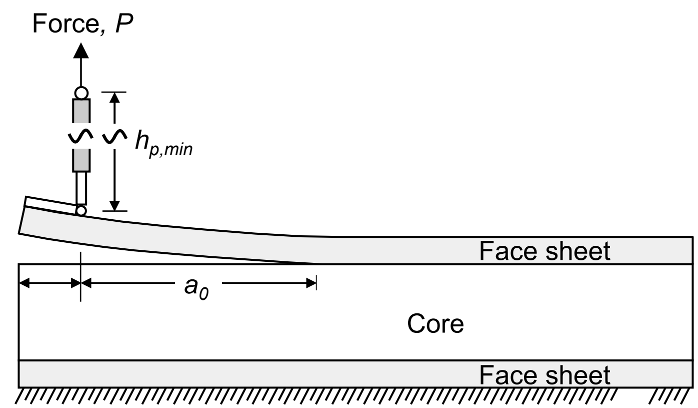


*Focus of this presentation
¶Society Member, Used with permission of ASTM

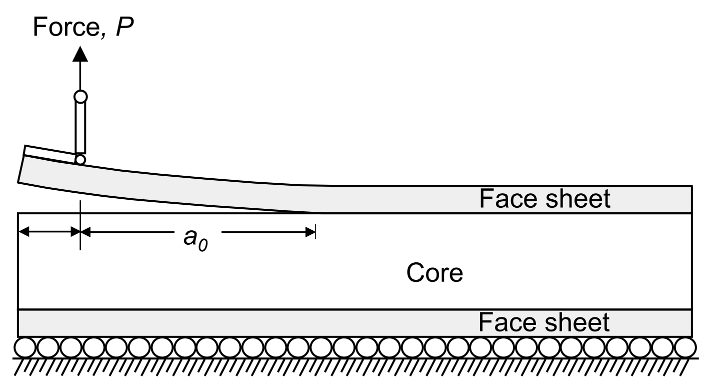
Coupon Test Standard Development - 1 of 2

- **Test standard development in ASTM committee D30 (WK 47682)**
  - **Characterize properties of face sheet/core interface**
  - **Mode-I disbond driving force assumed most critical for fracture control**
  - **Measure fracture toughness G_c**
  - **Single cantilever beam (SCB) type configuration was identified as the most appropriate test**
    - **Starter crack**
      - Teflon
      - Saw cut
    - **Simple loading fixture**
      - Loading offset fixture
      - Translatable carriage fixture
    - **Loading at disbond front independent of disbond length**
    - **Disbonding along or near the face sheet/core interface (no kinking into the core)**
    - **Disbond toughness can be calculated by using a compliance calibration procedure for data reduction**

Loading offset fixture



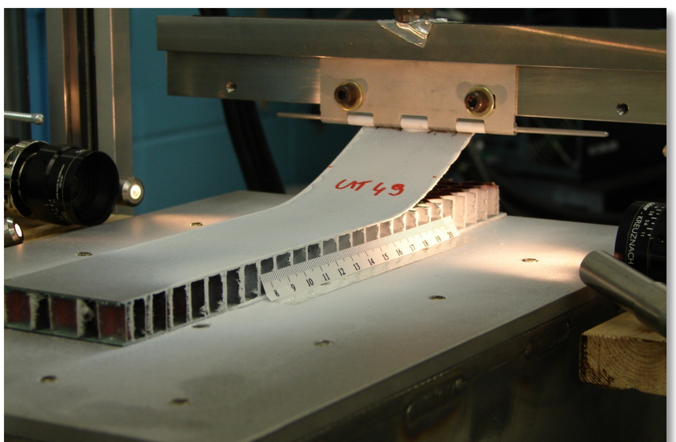
Translatable carriage fixture

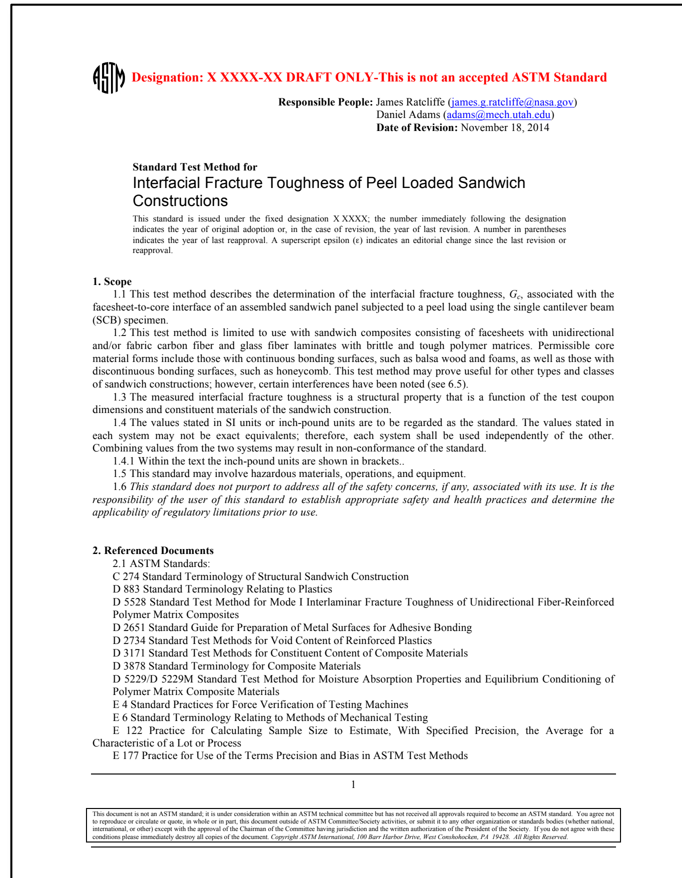


Coupon Test Standard Development – 2 of 2*

ASTM committee D30 (WK 47682)

- **Standardized test method for peel-dominated interfacial fracture toughness of sandwich constructions (draft)***
  - Main partners University of Utah and NASA Langley
  - ASTM draft¶ includes procedure to determine the SCB specimen dimensions (specimen length, face sheet thickness, initial disbond length)
  - Current round robin activity involves seven research laboratories in the US and Europe





Designation: X XXXX-XX DRAFT ONLY-This is not an accepted ASTM Standard

Responsible People: James Ratcliffe (james.g.ratcliffe@nasa.gov)
Daniel Adams (adams@mech.utah.edu)
Date of Revision: November 18, 2014

Standard Test Method for
Interfacial Fracture Toughness of Peel Loaded Sandwich Constructions

This standard is issued under the fixed designation X XXXX; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method describes the determination of the interfacial fracture toughness, G_c, associated with the facesheet-to-core interface of an assembled sandwich panel subjected to a peel load using the single cantilever beam (SCB) specimen.

1.2 This test method is limited to use with sandwich composites consisting of facesheets with unidirectional and/or fabric carbon fiber and glass fiber laminates with brittle and tough polymer matrices. Permissible core material forms include those with continuous bonding surfaces, such as balsa wood and foams, as well as those with discontinuous bonding surfaces, such as honeycomb. This test method may prove useful for other types and classes of sandwich constructions; however, certain interferences have been noted (see 6.5).

1.3 The measured interfacial fracture toughness is a structural property that is a function of the test coupon dimensions and constituent materials of the sandwich construction.

1.4 The values stated in SI units or inch-pound units are to be regarded as the standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance of the standard.

1.4.1 Within the text the inch-pound units are shown in brackets..

1.5 This standard may involve hazardous materials, operations, and equipment.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

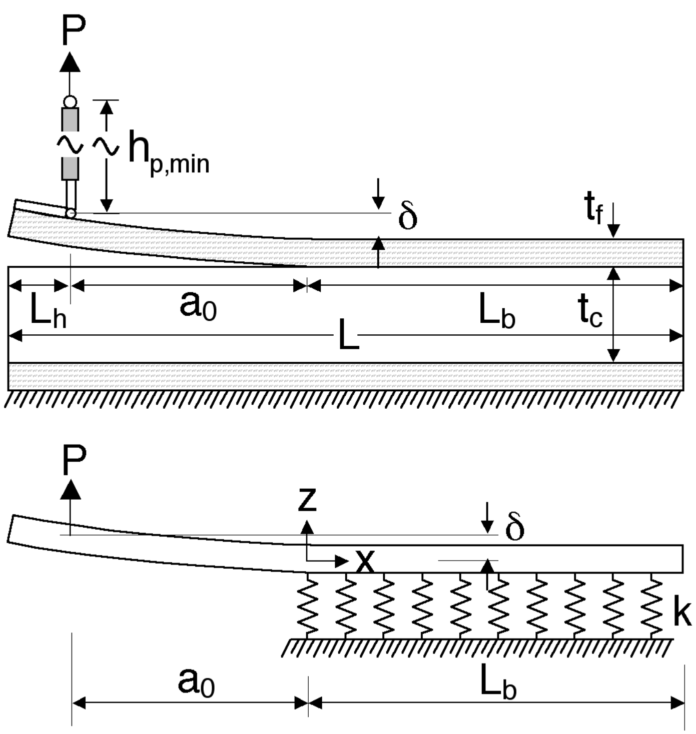
2.1 ASTM Standards:
C 274 Standard Terminology of Structural Sandwich Construction
D 883 Standard Terminology Relating to Plastics
D 5528 Standard Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites
D 2651 Standard Guide for Preparation of Metal Surfaces for Adhesive Bonding
D 2734 Standard Test Methods for Void Content of Reinforced Plastics
D 3171 Standard Test Methods for Constituent Content of Composite Materials
D 3878 Standard Terminology for Composite Materials
D 5229/D 5229M Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
E 4 Standard Practices for Force Verification of Testing Machines
E 6 Standard Terminology Relating to Methods of Mechanical Testing
E 122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

1

*D. Adams and B. Kuramoto, "Development and Evaluation of Fracture Mechanics Test Methods for Sandwich Composites," *JAMS 2012 Technical Review*, 2012.
*M. Rinker, J. Ratcliffe, D. Adams, and R. Krueger, "Characterizing Facesheet/Core Disbonding in Honeycomb," NASA/CR-2013-217959, 2013.
¶Society Member, Used with permission of ASTM

Single Cantilever Beam (SCB) Test Specimen

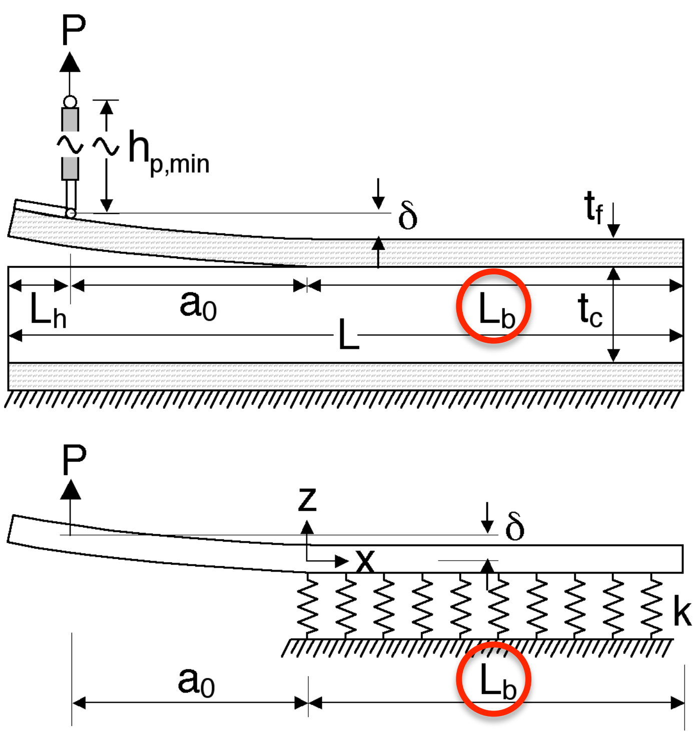
- **Beam sandwich laminate with pre-implanted starter disbond (Teflon, saw cut)**
- **Specimen dimensions sized to match known compliance solution and ensure proper specimen behavior**
- **Test configured to yield mode-I dominated disbond driving force**



SCB Specimen Parameter	Limitation
Intact portion of specimen	$L_b \geq L_{b,min} = 2.7\left[\frac{t_c t_f^3 E_f}{3E_c}\right]^{\frac{1}{4}}$
Initial disbond length (bending dominant deformation)	$a_0 \geq a_{min}^{bending} \approx \sqrt{\frac{30E_f t_f^2}{G_{xz,f}}} - 0.59L_{b,min}$ $a_0 \geq a_{min}^{compliance} = L_{b,min}$
Final disbond length	$a_{max} \geq a_0 + a_{prop}$
Face sheet thickness for small deformations	$t_f \geq t_f^{small\ disp} = \left[\frac{a_{max}}{\left(\frac{3a_{max}^2 E_f}{200G_c}\right)^{\frac{1}{4}} - \left(\frac{t_c E_f}{3E_c}\right)^{\frac{1}{4}}}\right]^{\frac{4}{3}}$
Face sheet thickness to prevent flexural failure of face sheet	$t_f \geq t_f^{strength} \approx \frac{6E_f G_c a_{max}^2}{\sigma_c^2}\left[a_{max} + \left(\frac{t_c (t_f^{small\ disp})^3 E_f}{3E_c}\right)^{\frac{1}{4}}\right]^{-2}$
Specimen length	$L \geq L_{min} = L_{hinge} + a_{max} + L_{b,min}$
Load application offset to ensure vertical load application	$h_p \geq h_{p,min} \approx 1.06a_{max}$

Single Cantilever Beam (SCB) Test Specimen

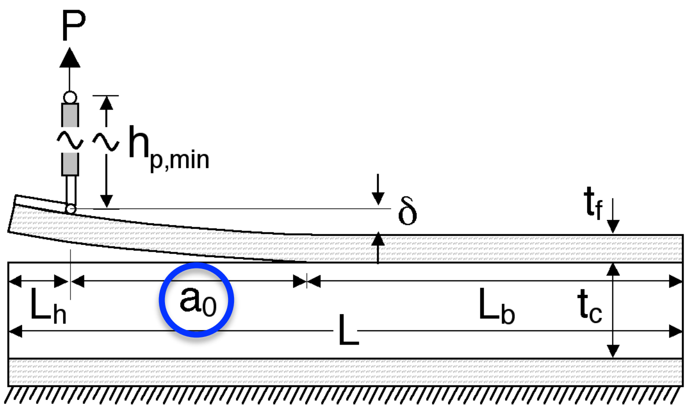
- **Beam sandwich laminate with pre-implanted starter disbond (Teflon, saw cut)**
- **Specimen dimensions sized to match known compliance solution and ensure proper specimen behavior**
- **Test configured to yield mode-I dominated disbond driving force**

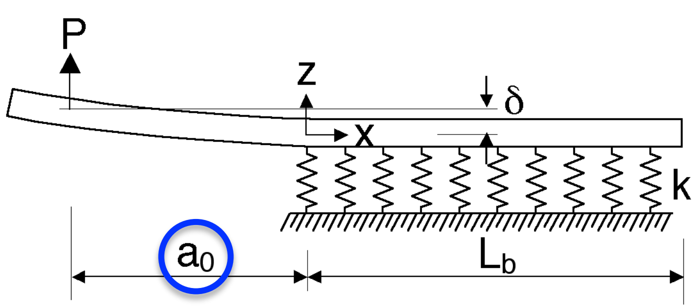


SCB Specimen Parameter	Limitation
Intact portion of specimen	$L_b \ge L_{b,min} = 2.7\left[\frac{t_c t_f^3 E_f}{3E_c}\right]^{\frac{1}{4}}$
Initial disbond length (bending dominant deformation)	$a_0 \ge a_{min}^{bending} \approx \sqrt{\frac{30E_f t_f^2}{G_{xz,f}}} - 0.59L_{b,min}$ $a_0 \ge a_{min}^{compliance} = L_{b,min}$
Final disbond length	$a_{max} \ge a_0 + a_{prop}$
Face sheet thickness for small deformations	$t_f \ge t_f^{small\ disp} = \left[\frac{a_{max}}{\left(\frac{3a_{max}^2 E_f}{200G_c}\right)^{\frac{1}{4}} - \left(\frac{t_c E_f}{3E_c}\right)^{\frac{1}{4}}}\right]^{\frac{4}{3}}$
Face sheet thickness to prevent flexural failure of face sheet	$t_f \ge t_f^{strength} \approx \frac{6E_f G_c a_{max}^2}{\sigma_c^2}\left[a_{max} + \left(\frac{t_c (t_f^{small\ disp})^3 E_f}{3E_c}\right)^{\frac{1}{4}}\right]^{-2}$
Specimen length	$L \ge L_{min} = L_{hinge} + a_{max} + L_{b,min}$
Load application offset to ensure vertical load application	$h_p \ge h_{p,min} \approx 1.06a_{max}$

Single Cantilever Beam (SCB) Test Specimen

- **Beam sandwich laminate with pre-implanted starter disbond (Teflon, saw cut)**
- **Specimen dimensions sized to match known compliance solution and ensure proper specimen behavior**
- **Test configured to yield mode-I dominated disbond driving force**

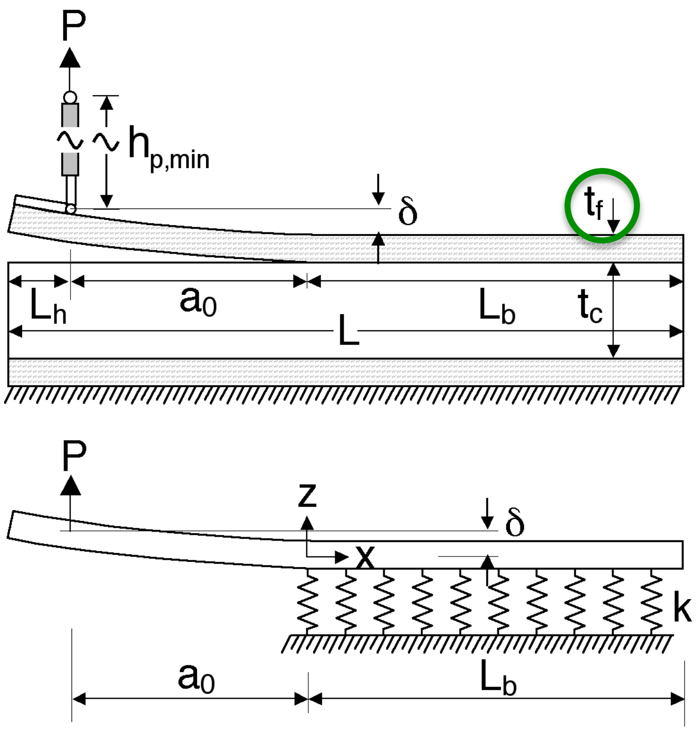




SCB Specimen Parameter	Limitation
Intact portion of specimen	$L_b \ge L_{b,min} = 2.7\left[\frac{t_c t_f^3 E_f}{3E_c}\right]^{\frac{1}{4}}$
Initial disbond length (bending dominant deformation)	$a_0 \ge a_{min}^{bending} \approx \sqrt{\frac{30E_f t_f^2}{G_{xz,f}}} - 0.59L_{b,min}$ $a_0 \ge a_{min}^{compliance} = L_{b,min}$
Final disbond length	$a_{max} \ge a_0 + a_{prop}$
Face sheet thickness for small deformations	$t_f \ge t_f^{small\ disp} = \left[\frac{a_{max}}{\left(\frac{3a_{max}^2 E_f}{200G_c}\right)^{\frac{1}{4}} - \left(\frac{t_c E_f}{3E_c}\right)^{\frac{1}{4}}}\right]^{\frac{4}{3}}$
Face sheet thickness to prevent flexural failure of face sheet	$t_f \ge t_f^{strength} \approx \frac{6E_f G_c a_{max}^2}{\sigma_c^2}\left[a_{max} + \left(\frac{t_c (t_f^{small\ disp})^3 E_f}{3E_c}\right)^{\frac{1}{4}}\right]^{-2}$
Specimen length	$L \ge L_{min} = L_{hinge} + a_{max} + L_{b,min}$
Load application offset to ensure vertical load application	$h_p \ge h_{p,min} \approx 1.06a_{max}$

Single Cantilever Beam (SCB) Test Specimen

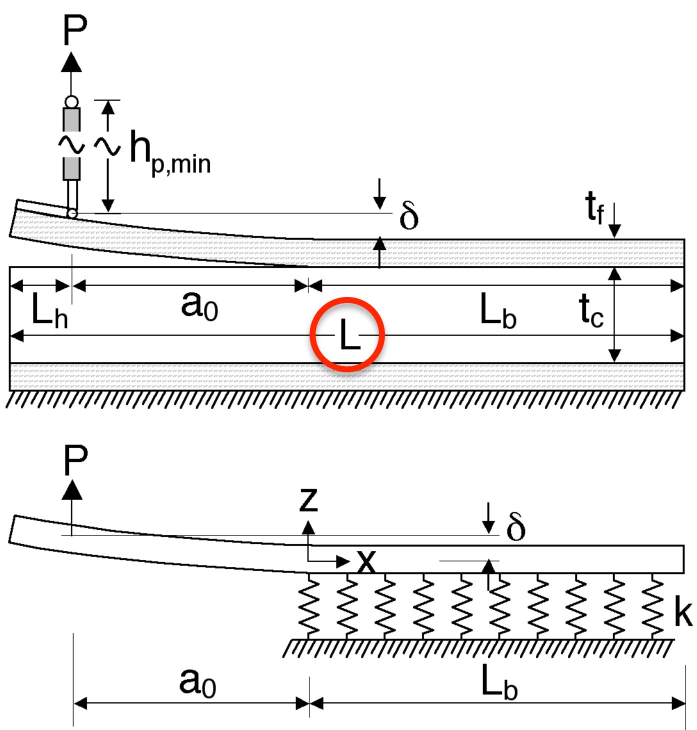
- **Beam sandwich laminate with pre-implanted starter disbond (Teflon, saw cut)**
- **Specimen dimensions sized to match known compliance solution and ensure proper specimen behavior**
- **Test configured to yield mode-I dominated disbond driving force**



SCB Specimen Parameter	Limitation
Intact portion of specimen	$L_b \geq L_{b,min} = 2.7\left[\frac{t_c t_f^3 E_f}{3E_c}\right]^{\frac{1}{4}}$
Initial disbond length (bending dominant deformation)	$a_0 \geq a_{min}^{bending} \approx \sqrt{\frac{30E_f t_f^2}{G_{xz,f}}} - 0.59L_{b,min}$ $a_0 \geq a_{min}^{compliance} = L_{b,min}$
Final disbond length	$a_{max} \geq a_0 + a_{prop}$
Face sheet thickness for small deformations	$t_f \geq t_f^{small\ disp} = \left[\frac{a_{max}}{\left(\frac{3a_{max}^2 E_f}{200G_c}\right)^{\frac{1}{4}} - \left(\frac{t_c E_f}{3E_c}\right)^{\frac{1}{4}}}\right]^{\frac{4}{3}}$
Face sheet thickness to prevent flexural failure of face sheet	$t_f \geq t_f^{strength} \approx \frac{6E_f G_c a_{max}^2}{\sigma_c^2}\left[a_{max} + \left(\frac{t_c (t_f^{small\ disp})^3 E_f}{3E_c}\right)^{\frac{1}{4}}\right]^{-2}$
Specimen length	$L \geq L_{min} = L_{hinge} + a_{max} + L_{b,min}$
Load application offset to ensure vertical load application	$h_p \geq h_{p,min} \approx 1.06a_{max}$

Single Cantilever Beam (SCB) Test Specimen

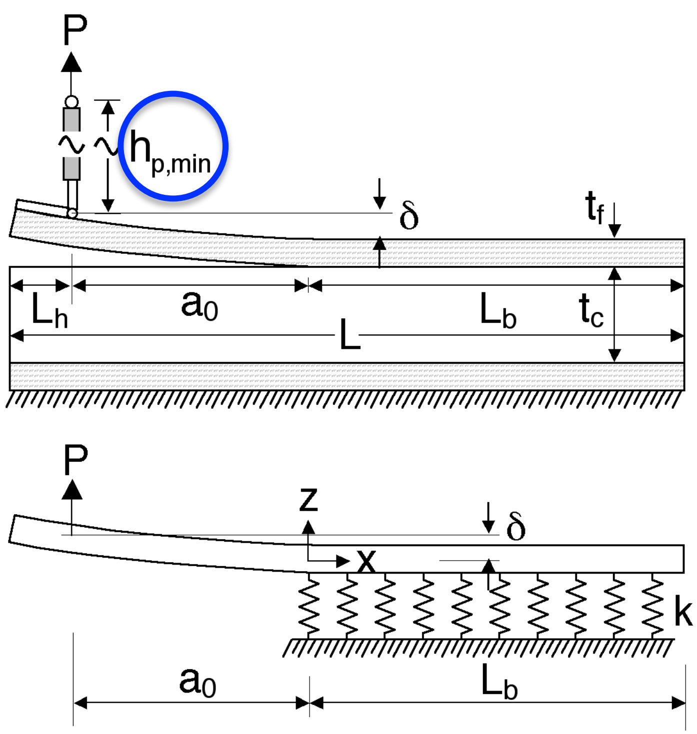
- **Beam sandwich laminate with pre-implanted starter disbond (Teflon, saw cut)**
- **Specimen dimensions sized to match known compliance solution and ensure proper specimen behavior**
- **Test configured to yield mode-I dominated disbond driving force**



SCB Specimen Parameter	Limitation
Intact portion of specimen	$L_b \ge L_{b,min} = 2.7\left[\frac{t_c t_f^3 E_f}{3E_c}\right]^{\frac{1}{4}}$
Initial disbond length (bending dominant deformation)	$a_0 \ge a_{min}^{bending} \approx \sqrt{\frac{30E_f t_f^2}{G_{xz,f}}} - 0.59L_{b,min}$ $a_0 \ge a_{min}^{compliance} = L_{b,min}$
Final disbond length	$a_{max} \ge a_0 + a_{prop}$
Face sheet thickness for small deformations	$t_f \ge t_f^{small\ disp} = \left[\frac{a_{max}}{\left(\frac{3a_{max}^2 E_f}{200G_c}\right)^{\frac{1}{4}} - \left(\frac{t_c E_f}{3E_c}\right)^{\frac{1}{4}}}\right]^{\frac{4}{3}}$
Face sheet thickness to prevent flexural failure of face sheet	$t_f \ge t_f^{strength} \approx \frac{6E_f G_c a_{max}^2}{\sigma_c^2}\left[a_{max} + \left(\frac{t_c (t_f^{small\ disp})^3 E_f}{3E_c}\right)^{\frac{1}{4}}\right]^{-2}$
Specimen length	$L \ge L_{min} = L_{hinge} + a_{max} + L_{b,min}$
Load application offset to ensure vertical load application	$h_p \ge h_{p,min} \approx 1.06a_{max}$

Single Cantilever Beam (SCB) Test Specimen

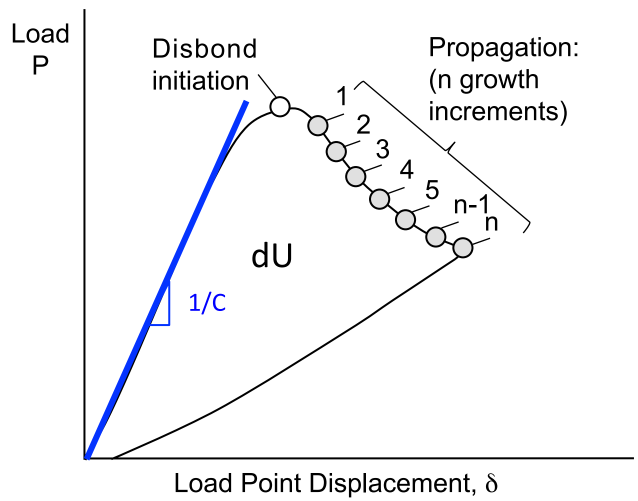
- **Beam sandwich laminate with pre-implanted starter disbond (Teflon, saw cut)**
- **Specimen dimensions sized to match known compliance solution and ensure proper specimen behavior**
- **Test configured to yield mode-I dominated disbond driving force**



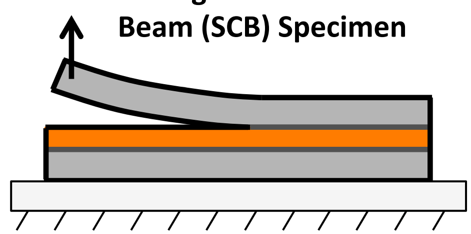
SCB Specimen Parameter	Limitation
Intact portion of specimen	$L_b \geq L_{b,min} = 2.7\left[\frac{t_c t_f^3 E_f}{3E_c}\right]^{\frac{1}{4}}$
Initial disbond length (bending dominant deformation)	$a_0 \geq a_{min}^{bending} \approx \sqrt{\frac{30 E_f t_f^2}{G_{xz,f}}} - 0.59 L_{b,min}$ $a_0 \geq a_{min}^{compliance} = L_{b,min}$
Final disbond length	$a_{max} \geq a_0 + a_{prop}$
Face sheet thickness for small deformations	$t_f \geq t_f^{small\ disp} = \left[\frac{a_{max}}{\left(\frac{3a_{max}^2 E_f}{200 G_c}\right)^{\frac{1}{4}} - \left(\frac{t_c E_f}{3E_c}\right)^{\frac{1}{4}}}\right]^{\frac{4}{3}}$
Face sheet thickness to prevent flexural failure of face sheet	$t_f \geq t_f^{strength} \approx \frac{6 E_f G_c a_{max}^2}{\sigma_c^2}\left[a_{max} + \left(\frac{t_c (t_f^{small\ disp})^3 E_f}{3E_c}\right)^{\frac{1}{4}}\right]^{-2}$
Specimen length	$L \geq L_{min} = L_{hinge} + a_{max} + L_{b,min}$
Load application offset to ensure vertical load application	$h_p \geq h_{p,min} \approx 1.06 a_{max}$

Interfacial Fracture Toughness Test Procedure

1. Load specimen (stroke control) and unload after required amount of disbonding
2. Record load/displacement response
3. Document changes in specimen compliance with disbond growth
4. Compute interfacial fracture toughness, G_c (initiation and propagation values)

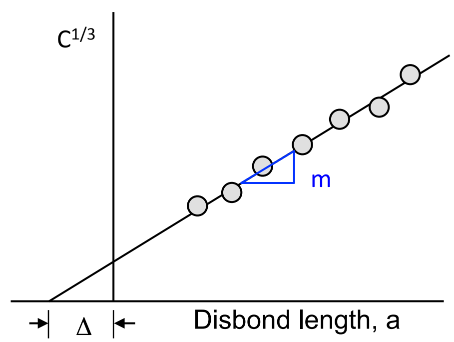


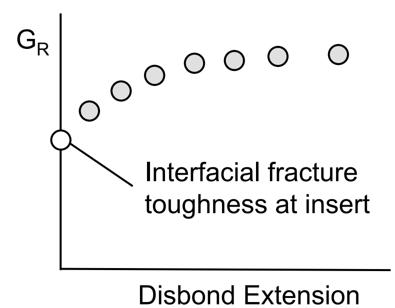
Single Cantilever Beam (SCB) Specimen



$$C = \frac{\delta}{P}, \quad C(a) = m^3 (a + \Delta)^3$$

$$G_C = \frac{P_C^2}{2b} \frac{dC}{da}$$





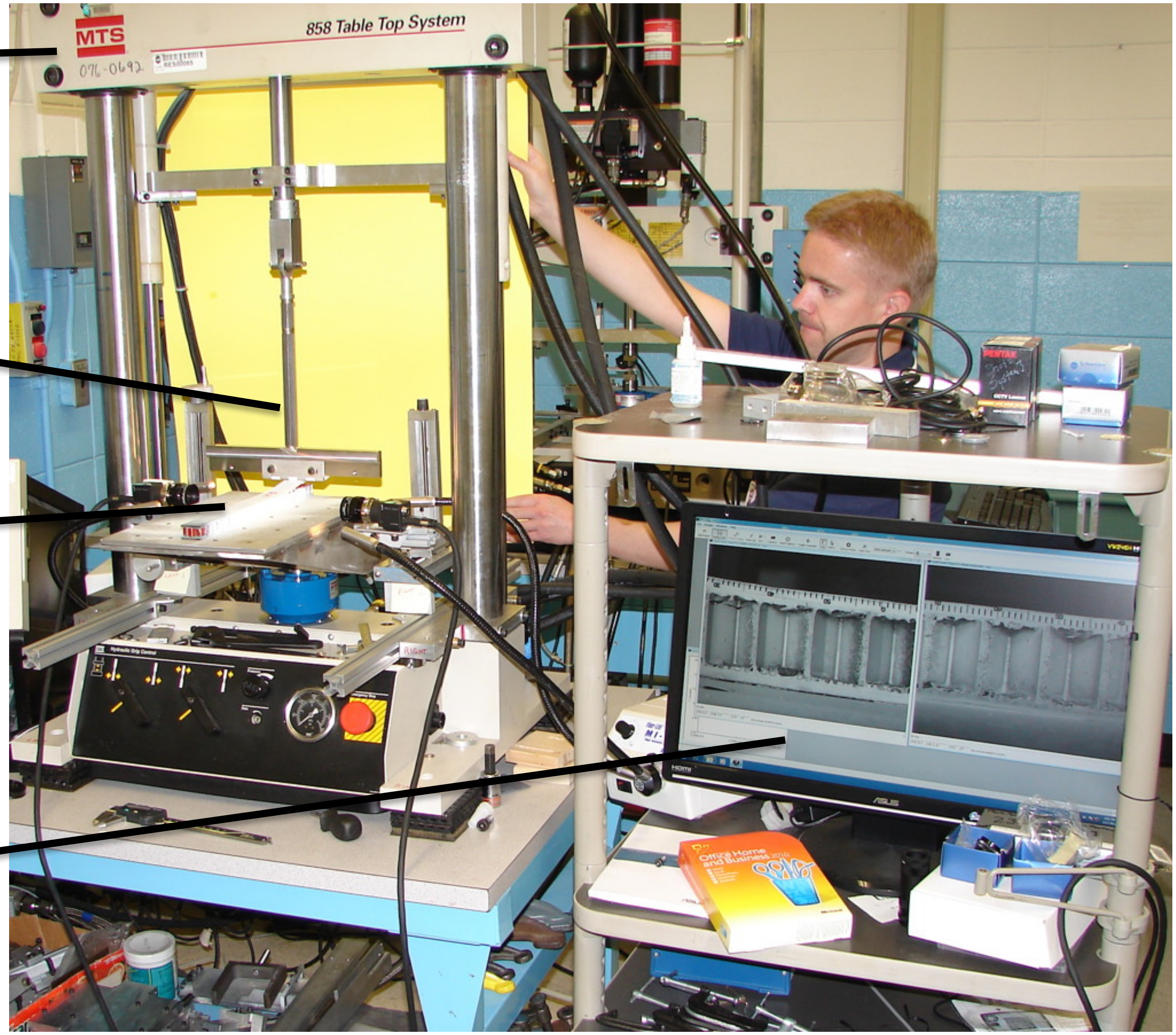
SCB Test Apparatus

Load frame

Test fixture

SCB
Specimen

Disbond
Tracking station



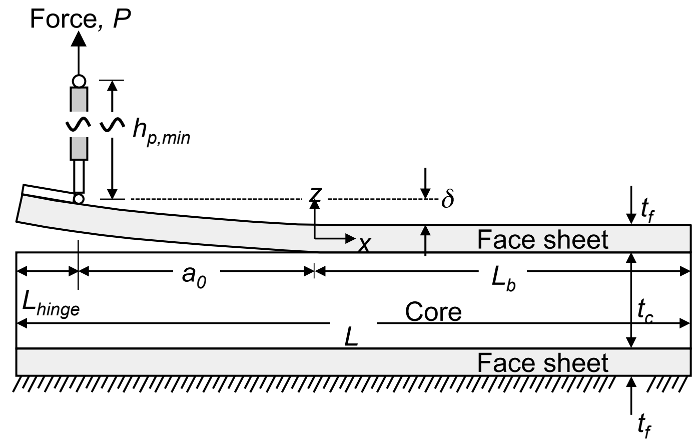
SCB Test Round Robin Exercise

SCB specimen configuration

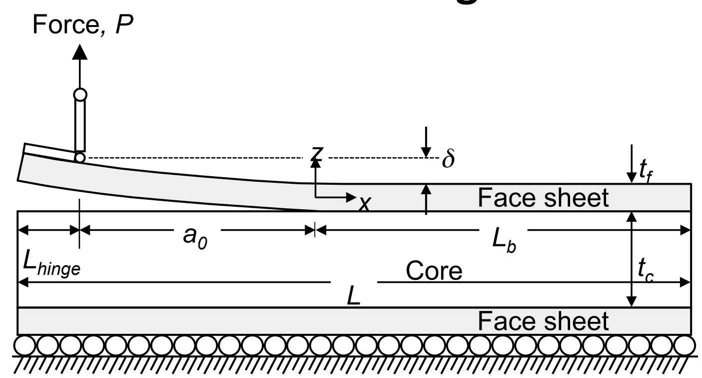
Baseline Specimen parameters	
a_0	12.7 mm (0.5”)
width, b	50.8 mm (2.0”)
$h_{p,min}$	500 mm (20”)
L	305 mm (12”)
L_{hinge}	25.4 mm (1.0”)
t_c	25.4 mm (1.0”)
t_f	0.772 mm (0.0304”)
Face sheet	T650/5320 PW Layup (4 plies): $[45/0]_s$ 0-dir along specimen length
Core	HRH-10: Cell size = 3.2 mm (0.125”) Density = 3lb/ft^3 (48kg/m^3)

Two loading fixture types considered to force a peel dominated behavior

Loading offset fixture



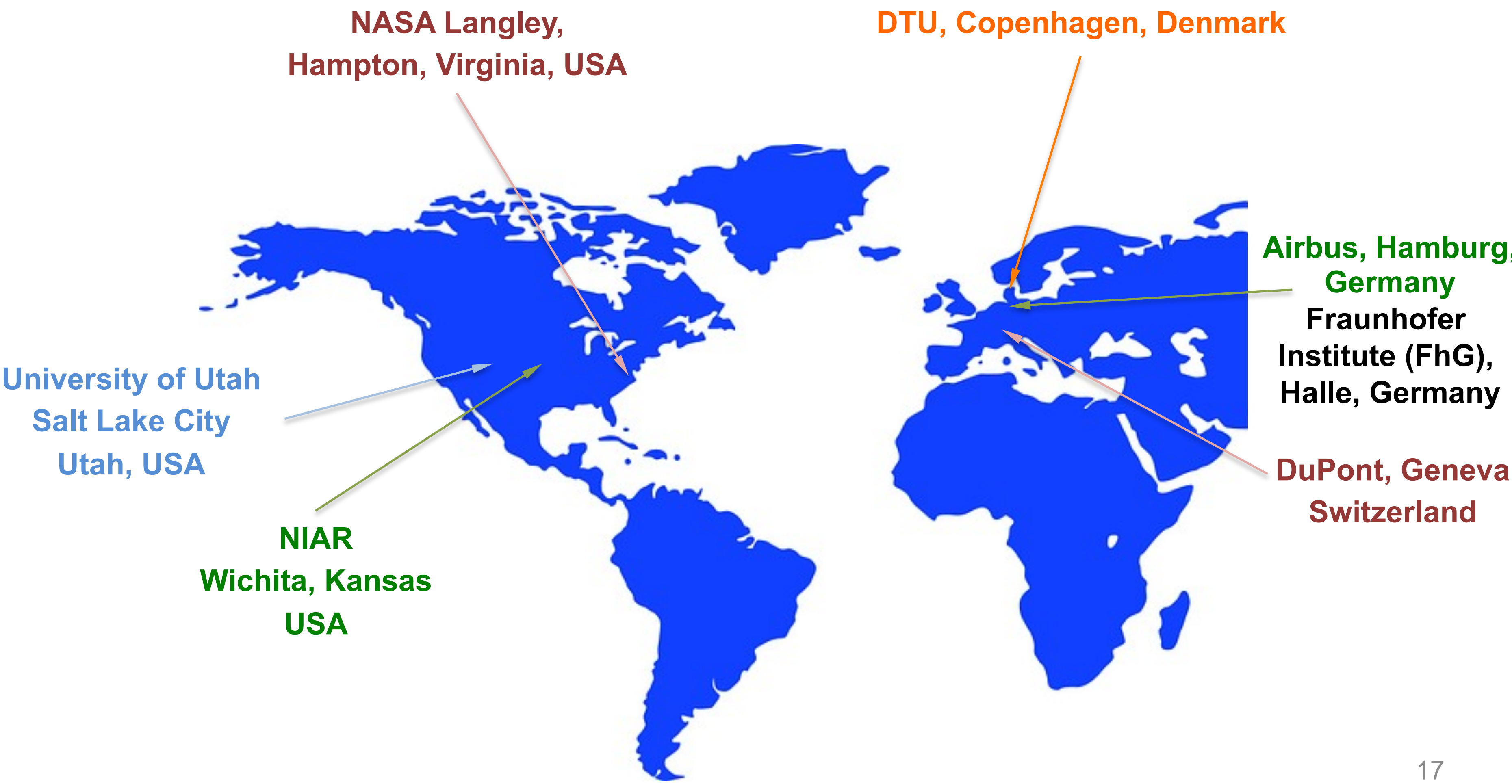
Translatable carriage fixture



SCB Test Round Robin Exercise

International Partners

- Inter-laboratory study being conducted to evaluate procedures in draft ASTM test standard



SCB Test Round Robin Exercise

Test matrix

Lab #	Test protocol	Number of Specimens: Baseline	Number of Specimens: Additional	L/W	Additional Studies: Starter Crack	Doubler	Fixture	Unloading	Test Speed loading (mm/min)	unloading
Lab 1 (Univ. Utah)		5A	10					0 mm	30	30
Lab 2 (NIAR)		5A	10		S		T			
Lab 3 (DuPont)	x	5A	10	W				0 mm	20?	30
Lab 4 (NASA)	x	5A	10			Y		0 mm	5	5
Lab 5 (Airbus)	x	5A	10	W				0 mm	20	30
Lab 6 (Fraunhofer)	x	5A	10		S	Y		0 mm		
Lab 7 (DTU)	x	5A	10			Y	T			

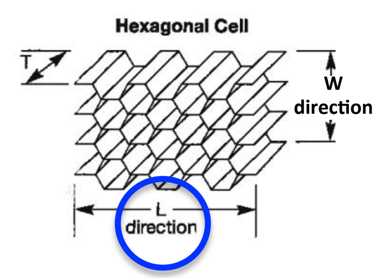
Specimen Category	Baseline	Additional
Dimensions	2 x 12-inch	
Crack Direction	L	W
Starter Crack	Teflon (T)	Saw Cut (S)
Insert Length	1.5-inch	
Doublers	No (N)	Yes (Y)
Fixture	Fixed (F)	Translate (T)
Test Speed loading unloading	5 mm/min 30 mm/min	20,30 mm/min 30, 5 mm/min
Δa for loop	10 mm (>3 cells)	
# of loops/cycles	>5	
Unloading	0 N	0 mm

Dimensional Nomenclature

T = Thickness, or cell depth

L = Ribbon direction

W = Long direction, or direction perpendicular to the ribbon



SCB Test Round Robin Exercise

Test matrix

Lab #	Test protocol	Number of Specimens		Additional Studies						
		Baseline	Additional	L/W	Starter Crack	Doubler	Fixture	Unloading	Test Speed loading (mm/min)	unloading
Lab 1 (Univ. Utah)		5A	10					0 mm	30	30
Lab 2 (NIAR)		5A	10		S		T			
Lab 3 (DuPont)	x	5A	10	W				0 mm	20?	30
Lab 4 (NASA)	x	5A	10			Y		0 mm	5	5
Lab 5 (Airbus)	x	5A	10	W				0 mm	20	30
Lab 6 (Fraunhofer)	x	5A	10		S	Y		0 mm		
Lab 7 (DTU)	x	5A	10			Y	T			

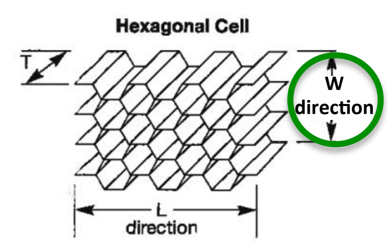
Specimen Category	Baseline	Additional
Dimensions	2 x 12-inch	
Crack Direction	L	W
Starter Crack	Teflon (T)	Saw Cut (S)
Insert Length	1.5-inch	
Doublers	No (N)	Yes (Y)
Fixture	Fixed (F)	Translate (T)
Test Speed loading unloading	 5 mm/min 30 mm/min	 20,30 mm/min 30, 5 mm/min
Δa for loop	10 mm (>3 cells)	
# of loops/cycles	>5	
Unloading	0 N	0 mm

Dimensional Nomenclature

T = Thickness, or cell depth

L = Ribbon direction

W = Long direction, or direction perpendicular to the ribbon

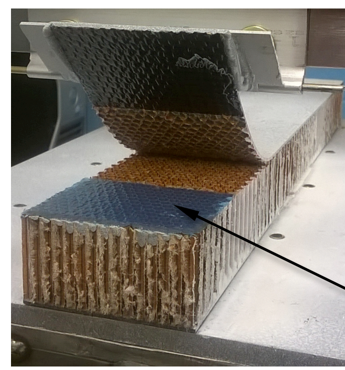


SCB Test Round Robin Exercise

Test matrix

Lab #	Test protocol	Number of Specimens		Additional Studies						
		Baseline	Additional	L/W	Starter Crack	Doubler	Fixture	Unloading	Test Speed loading (mm/min)	unloading
Lab 1 (Univ. Utah)		5A	10					0 mm	30	30
Lab 2 (NIAR)		5A	10		S		T			
Lab 3 (DuPont)	x	5A	10	W				0 mm	20?	30
Lab 4 (NASA)	x	5A	10			Y		0 mm	5	5
Lab 5 (Airbus)	x	5A	10	W				0 mm	20	30
Lab 6 (Fraunhofer)	x	5A	10		S	Y		0 mm		
Lab 7 (DTU)	x	5A	10			Y	T			

Specimen Category	Baseline	Additional
Dimensions	2 x 12-inch	
Crack Direction	L	W
Starter Crack	Teflon (T)	Saw Cut (S)
Insert Length	1.5-inch	
Doublers	No (N)	Yes (Y)
Fixture	Fixed (F)	Translate (T)
Test Speed loading unloading	5 mm/min 30 mm/min	20,30 mm/min 30, 5 mm/min
Δa for loop	10 mm (>3 cells)	
# of loops/cycles	>5	
Unloading	0 N	0 mm



Teflon or saw cut

SCB Test Round Robin Exercise

Test matrix

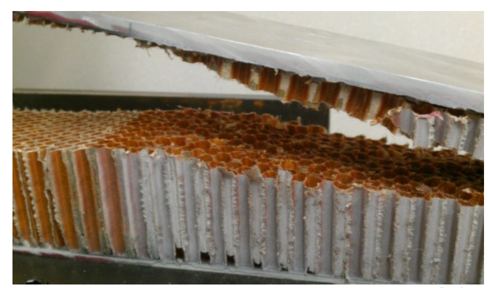
Lab #	Test protocol	Number of Specimens		Additional Studies						
		Baseline	Additional	L/W	Starter Crack	Doubler	Fixture	Unloading	Test Speed loading (mm/min)	unloading
Lab 1 (Univ. Utah)		5A	10					0 mm	30	30
Lab 2 (NIAR)		5A	10		S		T			
Lab 3 (DuPont)	x	5A	10	W				0 mm	20?	30
Lab 4 (NASA)	x	5A	10			Y		0 mm	5	5
Lab 5 (Airbus)	x	5A	10	W				0 mm	20	30
Lab 6 (Fraunhofer)	x	5A	10		S	Y		0 mm		
Lab 7 (DTU)	x	5A	10			Y	T			

Specimen Category	Baseline	Additional
Dimensions	2 x 12-inch	
Crack Direction	L	W
Starter Crack	Teflon (T)	Saw Cut (S)
Insert Length	1.5-inch	
Doublers	No (N)	Yes (Y)
Fixture	Fixed (F)	Translate (T)
Test Speed loading unloading	 5 mm/min 30 mm/min	 20,30 mm/min 30, 5 mm/min
Δa for loop	10 mm (>3 cells)	
# of loops/cycles	>5	
Unloading	0 N	0 mm

Thin face sheet tested without doubler

Thin face sheet tested with doubler

- **Reduces face sheet damage**
- **Creates unwanted core facture due to shear component**

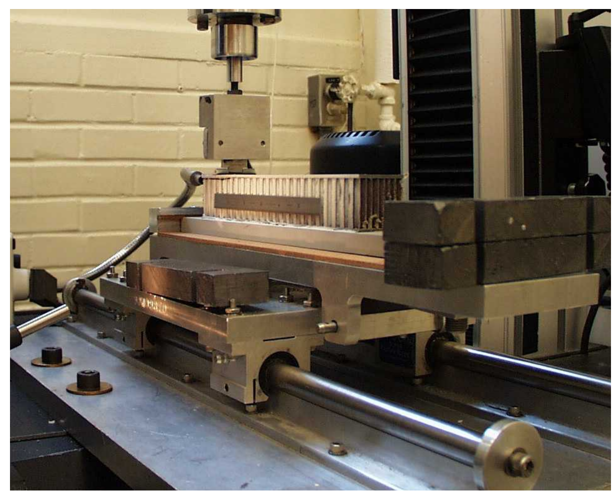


SCB Test Round Robin Exercise

Test matrix

Lab #	Test protocol	Number of Specimens		Additional Studies						
		Baseline	Additional	L/W	Starter Crack	Doubler	Fixture	Unloading	Test Speed loading (mm/min)	unloading
Lab 1 (Univ. Utah)		5A	10					0 mm	30	30
Lab 2 (NIAR)		5A	10		S		T			
Lab 3 (DuPont)	x	5A	10	W				0 mm	20?	30
Lab 4 (NASA)	x	5A	10			Y		0 mm	5	5
Lab 5 (Airbus)	x	5A	10	W				0 mm	20	30
Lab 6 (Fraunhofer)	x	5A	10		S	Y		0 mm		
Lab 7 (DTU)	x	5A	10			Y	T			

Specimen Category	Baseline	Additional
Dimensions	2 x 12-inch	
Crack Direction	L	W
Starter Crack	Teflon (T)	Saw Cut (S)
Insert Length	1.5-inch	
Doublers	No (N)	Yes (Y)
Fixture	Fixed (F)	Translate (T)
Test Speed loading unloading	 5 mm/min 30 mm/min	 20,30 mm/min 30, 5 mm/min
Δa for loop	10 mm (>3 cells)	
# of loops/cycles	>5	
Unloading	0 N	0 mm

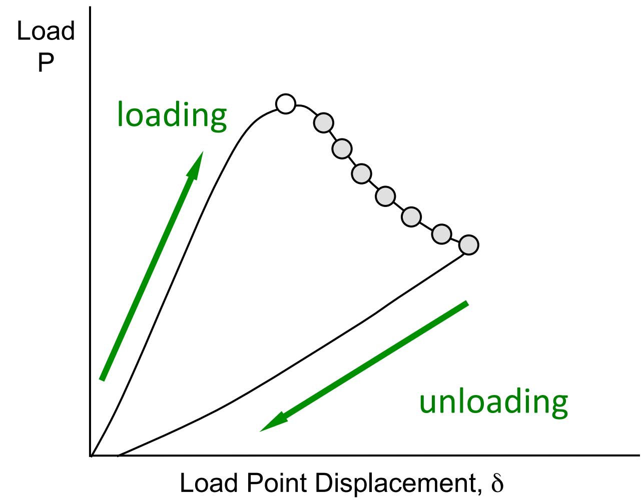


SCB Test Round Robin Exercise

Test matrix

Lab #	Test protocol	Number of Specimens		Additional Studies						
		Baseline	Additional	L/W	Starter Crack	Doubler	Fixture	Unloading	Test Speed loading (mm/min)	unloading
Lab 1 (Univ. Utah)		5A	10					0 mm	30	30
Lab 2 (NIAR)		5A	10		S		T			
Lab 3 (DuPont)	x	5A	10	W				0 mm	20?	30
Lab 4 (NASA)	x	5A	10			Y		0 mm	5	5
Lab 5 (Airbus)	x	5A	10	W				0 mm	20	30
Lab 6 (Fraunhofer)	x	5A	10		S	Y		0 mm		
Lab 7 (DTU)	x	5A	10			Y	T			

Specimen Category	Baseline	Additional
Dimensions	2 x 12-inch	
Crack Direction	L	W
Starter Crack	Teflon (T)	Saw Cut (S)
Insert Length	1.5-inch	
Doublers	No (N)	Yes (Y)
Fixture	Fixed (F)	Translate (T)
Test Speed loading unloading	5 mm/min 30 mm/min	20,30 mm/min 30, 5 mm/min
Δa for loop	10 mm (>3 cells)	
# of loops/cycles	>5	
Unloading	0 N	0 mm



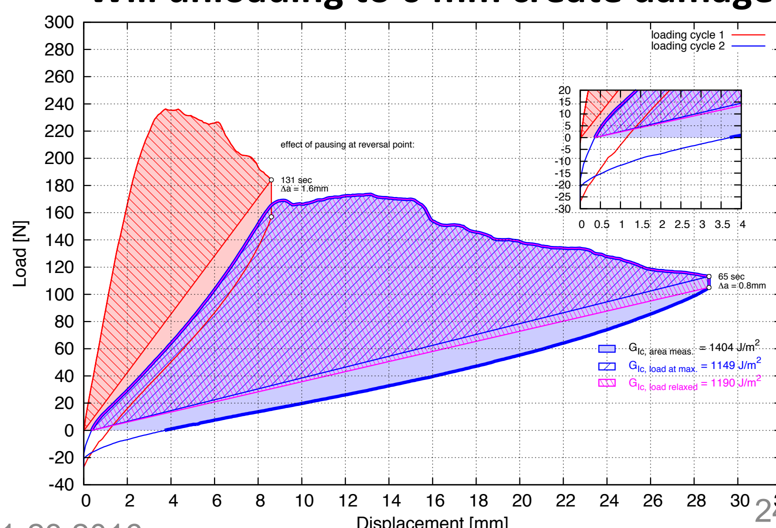
SCB Test Round Robin Exercise

Test matrix

Lab #	Test protocol	Number of Specimens		Additional Studies						
		Baseline	Additional	L/W	Starter Crack	Doubler	Fixture	Unloading	Test Speed loading (mm/min)	unloading
Lab 1 (Univ. Utah)		5A	10					0 mm	30	30
Lab 2 (NIAR)		5A	10		S		T			
Lab 3 (DuPont)	x	5A	10	W				0 mm	20?	30
Lab 4 (NASA)	x	5A	10			Y		0 mm	5	5
Lab 5 (Airbus)	x	5A	10	W				0 mm	20	30
Lab 6 (Fraunhofer)	x	5A	10		S	Y		0 mm		
Lab 7 (DTU)	x	5A	10			Y	T			

Specimen Category	Baseline	Additional
Dimensions	2 x 12-inch	
Crack Direction	L	W
Starter Crack	Teflon (T)	Saw Cut (S)
Insert Length	1.5-inch	
Doublers	No (N)	Yes (Y)
Fixture	Fixed (F)	Translate (T)
Test Speed loading unloading	5 mm/min 30 mm/min	20,30 mm/min 30, 5 mm/min
Δa for loop	10 mm (>3 cells)	
# of loops/cycles	>5	
Unloading	0 N	0 mm

Will unloading to 0 mm create damage?

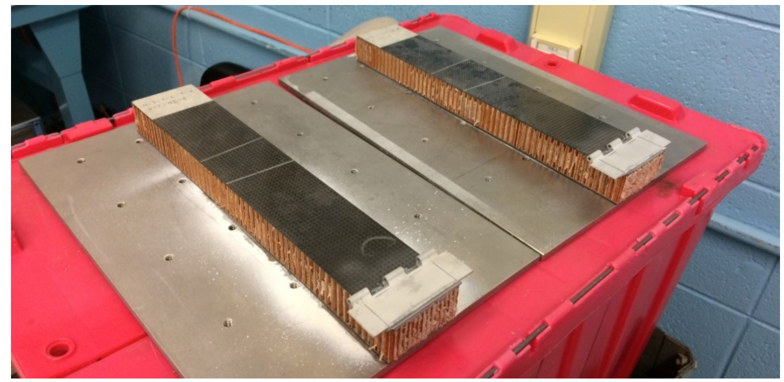


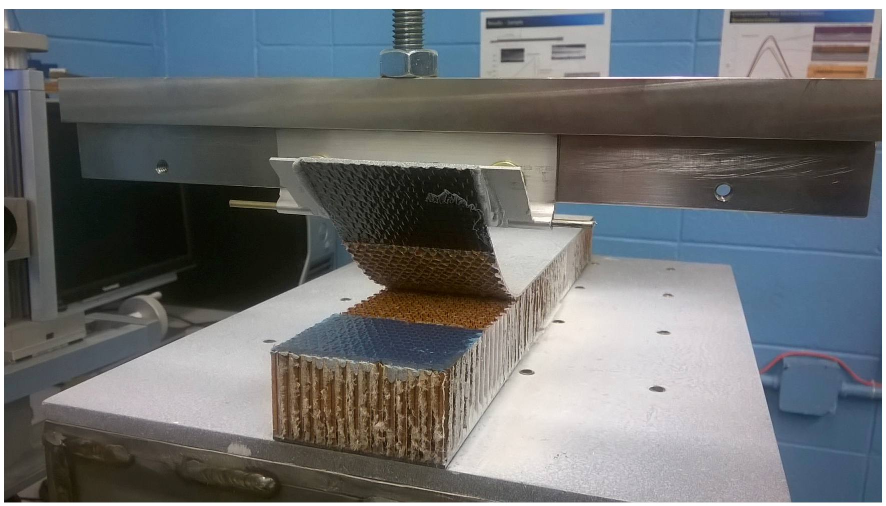
SCB Test Round Robin Exercise

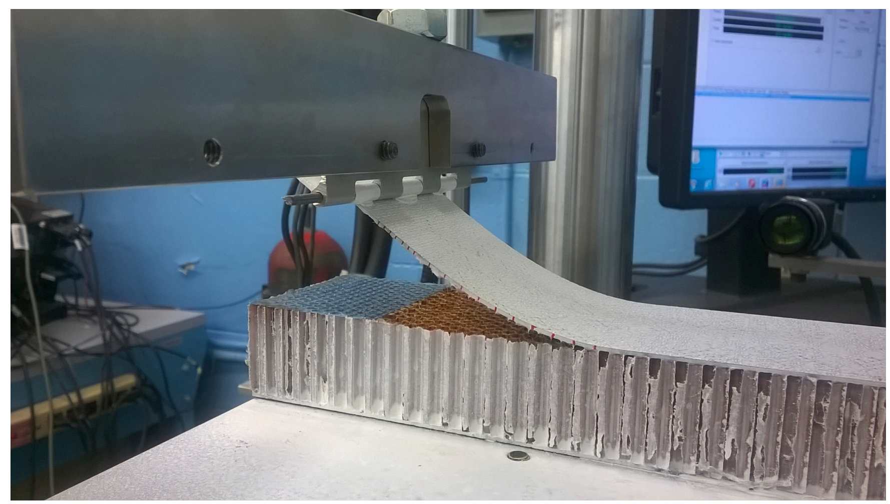
Testing at NASA Langley Research Center

- **Specimens manufactured at National Institute for Aviation Research (NIAR)**
- **NASA LaRC received 15 specimens**
    - 5 tests with 3 different conditions
    - Testing in progress
    - Testing performed in collaboration with FAA Tech Center in Atlantic City

Test specimen preparation







*pictures Ronald Krueger and Zhi Chen

Closing Remarks

- Face sheet/core disbonding significant damage mode of sandwich composites
- Mode-I disbond driving force assumed most critical for fracture control
- Test method for measuring mode-I interfacial fracture toughness developed into a draft ASTM test standard
- Round robin exercise composed of 7 international laboratories being conducted to evaluate draft standard
- Work ties in with activities in the broader community concerned with sandwich disbonding