WICHITA STATE UNIVERSITY

NATIONAL INSTITUTE FOR AVIATION RESEARCH

An experimental presentation on the effects of poor design or implementation of modifications involving composite materials

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Presented at the FAA Workshop on Modifications and Alterations Affecting Composite Parts or Composite Structure
July 19-20, 2016 at the National Center for Aviation Training in Wichita, KS

Problem Statement and Objectives

- The FAA is trying to get people to understand the effects of a poorly designed modification or repair
- There are DERs who think they can mix any two materials together and have compatibility, or use any process specification
- Showing them some experimental effects may be a more effective way in getting through to them
  - Some contents were created at NIAR especially for this workshop
  - Other contents were obtained from existing sources
- To ensure durable structures, proper material and process specifications must be followed.

Agenda

- Stiffness mismatch[FL1]
- CTE mismatch, warped panel[FL1]
- CTE mismatch, bolted panels[FL2]
- Galvanic corrosion[FL2]
- Fresh vs. expired prepreg[FL1]
- Lightning strike, paint thickness effects[FL2]
- Surface preparation effects
  - Surface moisture[FL1]
  - Partially cleaned prior to bonding[FL1]
  - Contamination from peel-ply[FL1]
  - Contamination from release agent[FL1]

FL1: Content created at NIAR especially for this workshop

FL2: Content obtained from existing sources

Stiffness Mismatch - Examples of Poor Design in Bonded Repairs

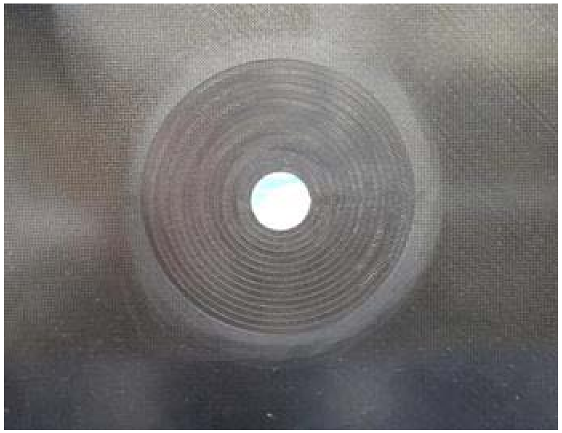
Prepreg *Highly Stiff* Repair Patch

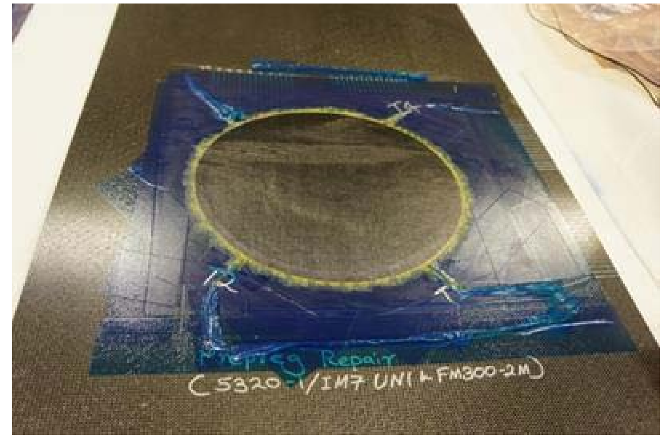
Versus

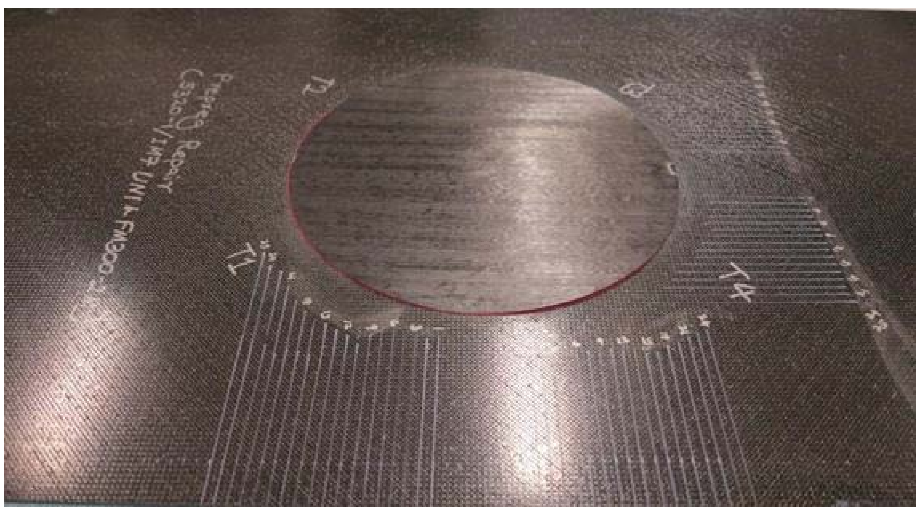
Wet Lay-Up *Soft* Patch

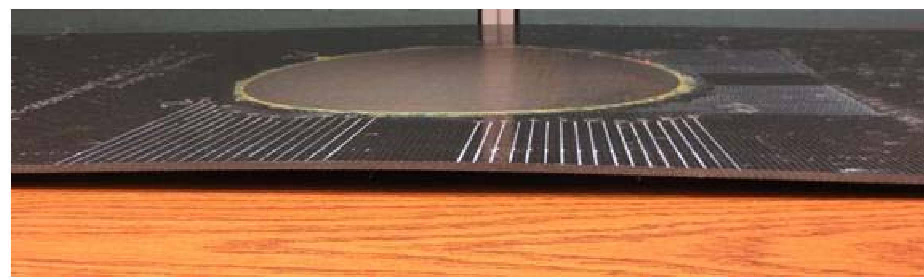
Content created by Dr. Lamia Salah

Prepreg Highly Stiff Repair Patch









Warped Repair Panel due to Stiffness/CTE Mismatch

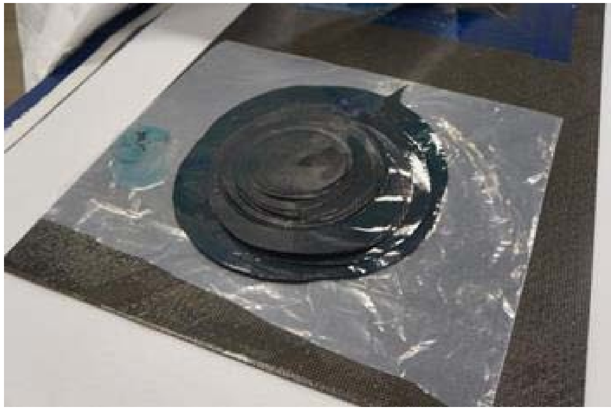
Parent: Cytec T650/ 5320-1 PW, Quasi

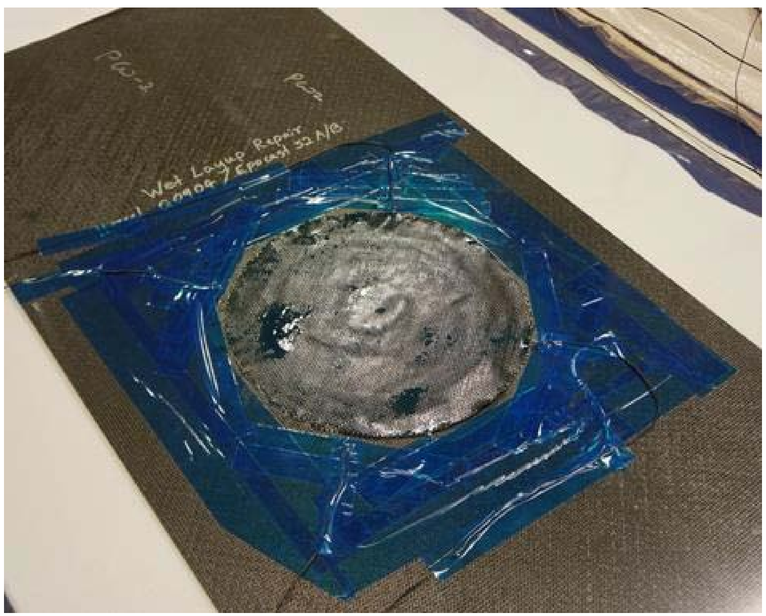
Repair: Cytec IM7/5320-1 UNI, Highly Stiff

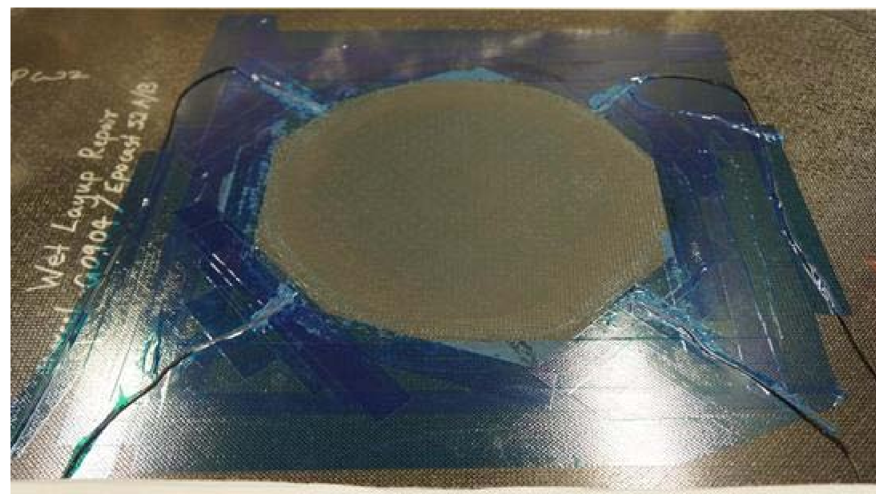
Content created by Dr. Lamia Salah

strain distribution showing stiffness mismatch between parent and repair

Wet Lay-Up Soft Patch







Parent: Cytec T650/ 5320-1 PW, Quasi

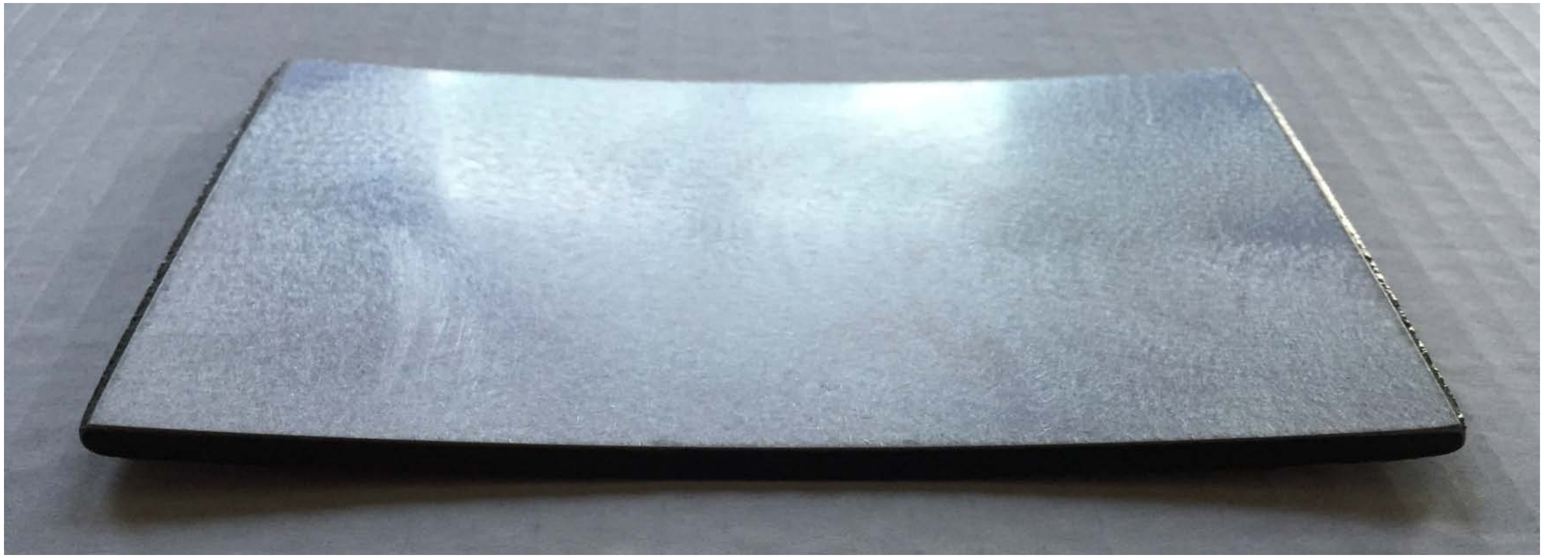
Repair: G904/ Epocast 52A/B wet lay-up, Soft Patch

Content created by Dr. Lamia Salah

strain distribution showing stiffness mismatch between parent and repair

CTE Mismatch, Warped Panel

- A demonstration test panel: 7” by 4”, 12 plies of carbon unidirectional tape cured onto a 0.064” thick aluminum
- Causes warpage and thermally induced stresses

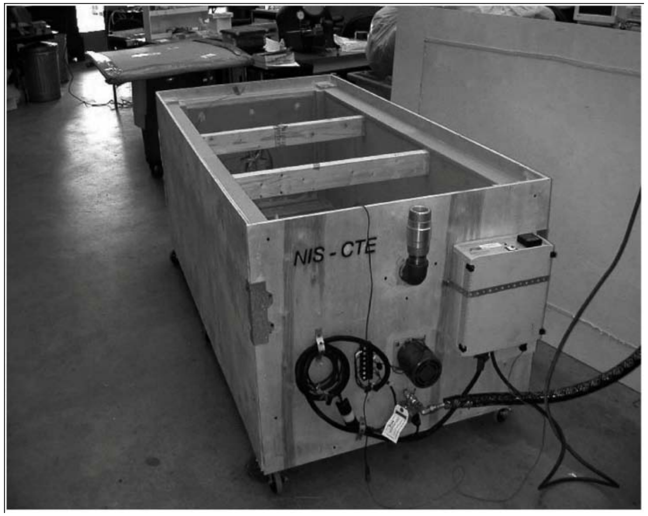


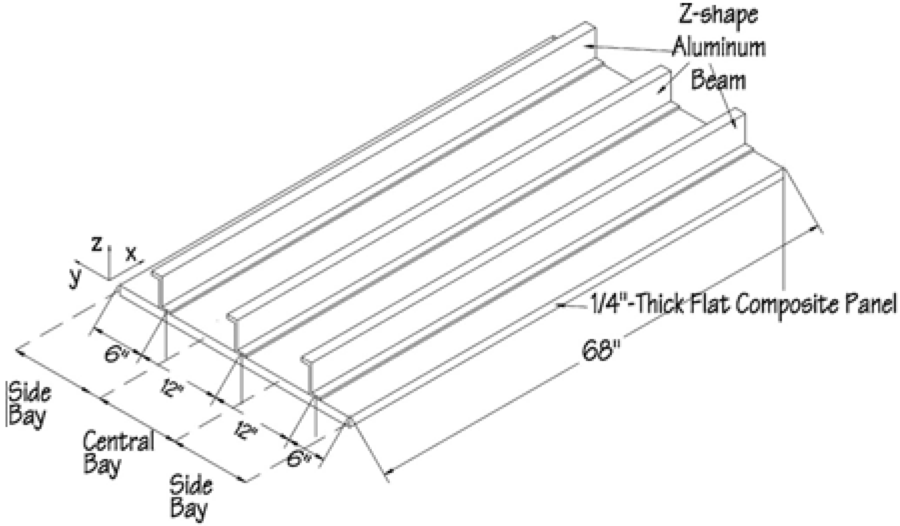
- CTE mismatch can cause significant stresses and strains.
  - CTE of Al 2024 ≈ 12.7 me/^{0}F
  - CTE of composite ≈ 1.5 me/^{0}F
- CTE mismatch problem is more pronounced in large and/or thick structures that operate at wide temperature range and/or cured at high temperature

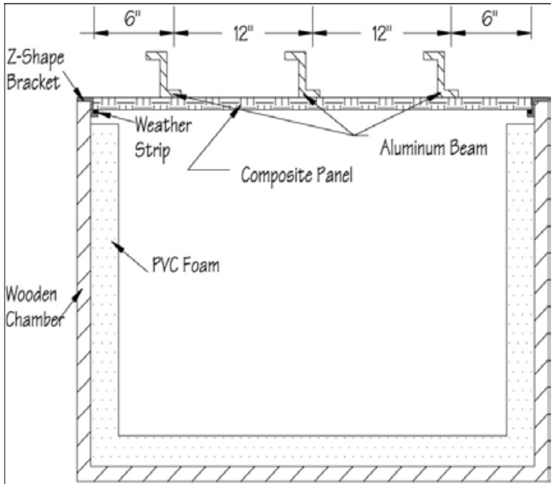
CTE Mismatch, Fastened Hybrid Structure

- An example of thermally-induced stress modelling comparison with test results
- Chihdar Yang, Wenjun Sun, Waruna Seneviratne, and Ananthram K. Shashidhar, “Thermally Induced Loads of Fastened Hybrid Composite/Aluminum Structures,” JOURNAL OF AIRCRAFT, Vol. 45, No. 2, March–April 2008

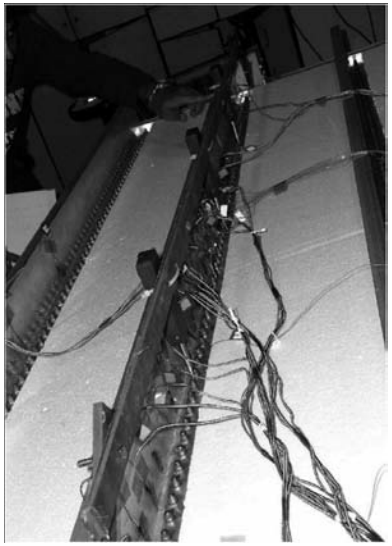
CTE Mismatch, Fastened Hybrid Structure





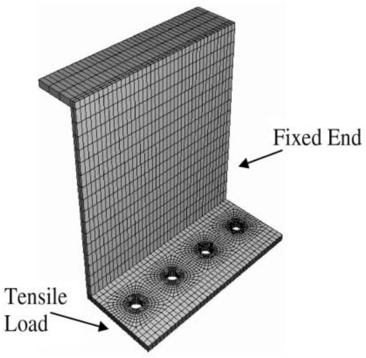


Experimental Setup



Chihdar Yang, Wenjun Sun, Waruna Seneviratne, and Ananthram K. Shashidhar, "Thermally Induced Loads of Fastened Hybrid Composite/Aluminum Structures," JOURNAL OF AIRCRAFT, Vol. 45, No. 2, March–April 2008

CTE Mismatch, Fastened Hybrid Structure



a) Boundary condition

b) Displacement contour

Fig.12 Mechanical finite element model of Z-shaped aluminum beam with four units.

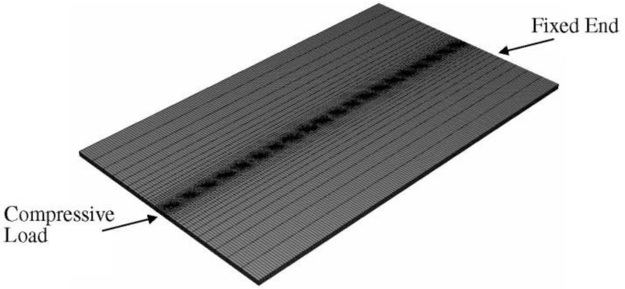


Fig. 13 Mechanical finite element model of flat composite panel with 20 units.

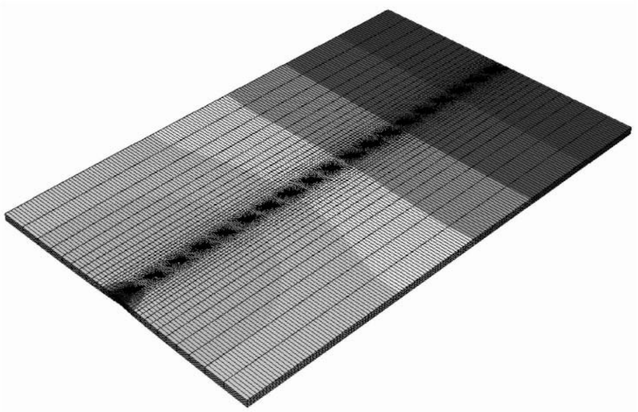


Fig.14 Displacement contour of flat composite panel with 20 units

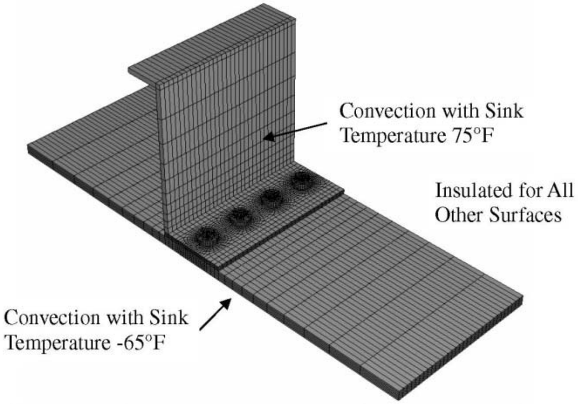


Fig. 15 Thermal finite element model of aluminum/composite assembly with four units.

CTE Mismatch, Fastened Hybrid Structure

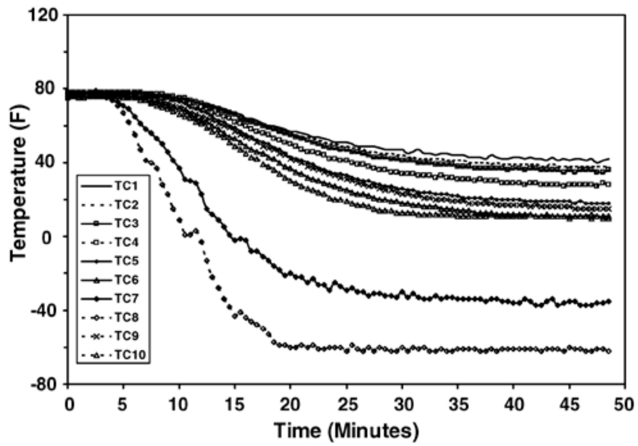


Fig. 17 **Typical temperature history.**

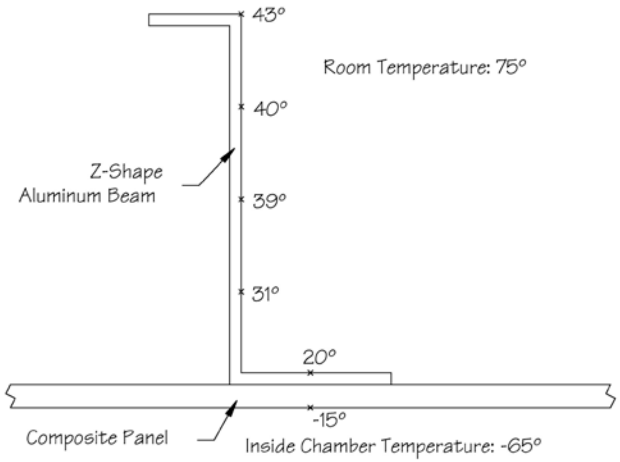


Fig. 19 **Temperature profile determined from thermal finite element model.**

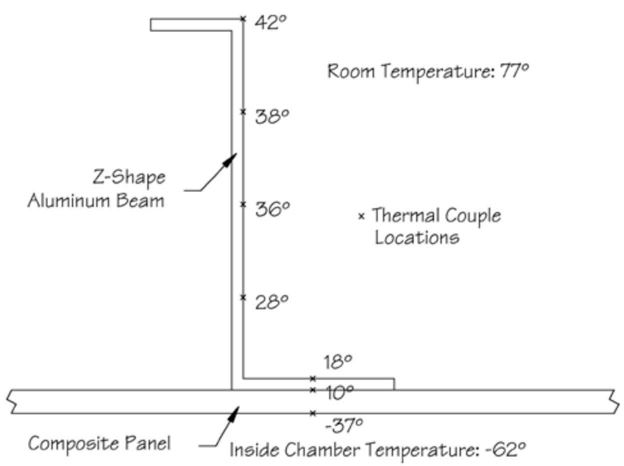


Fig. 18 **Average temperature distribution of tests.**

- Ability to understand steady-state and transient conditions

CTE Mismatch, Fastened Hybrid Structure

- Ability to identify locations of highly stressed areas, e.g. the peak stress of the aluminum beam occurs at the center of the assembly

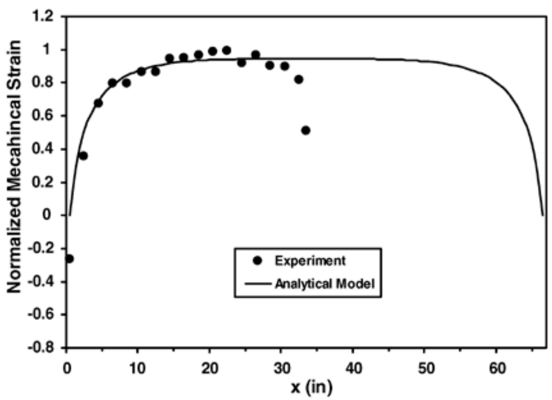


Fig. 20 Mechanical strains comparison between tests and analytical model for 66-fastener setup (65-in. fastened length).

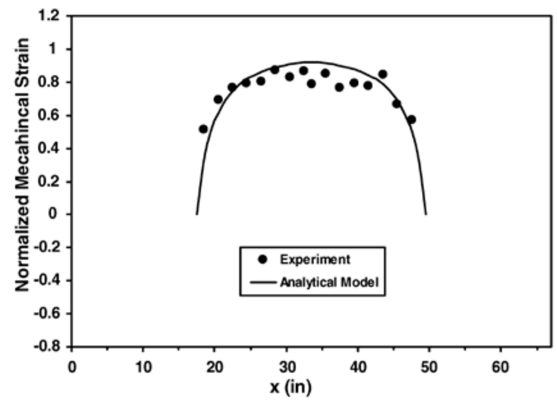


Fig. 22 Mechanical strains comparison between tests and analytical model for 32-fastener setup (31-in. fastened length).

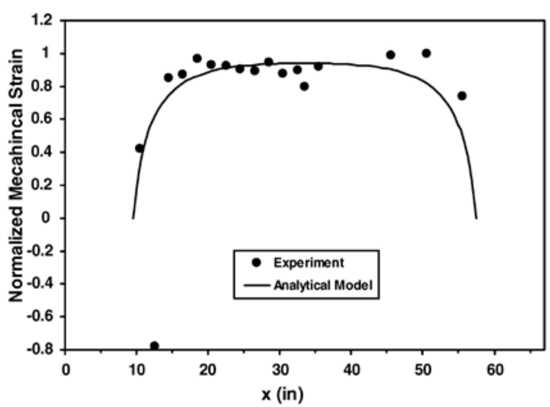


Fig. 21 Mechanical strains comparison between tests and analytical model for 48-fastener setup (47-in. fastened length).

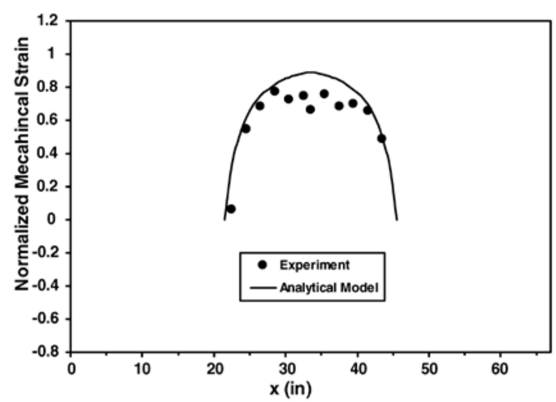


Fig. 23 Mechanical strains comparison between tests and analytical model for 24-fastener setup (23-in. fastened length).

CTE Mismatch, Fastened Hybrid Structure

- However, the load transfer through the fasteners shows the opposite trend. The end fasteners take the highest load, and the fasteners at the center carry very little load. The peak fastener load vs fastened length of the assembly is shown in Fig. 28.

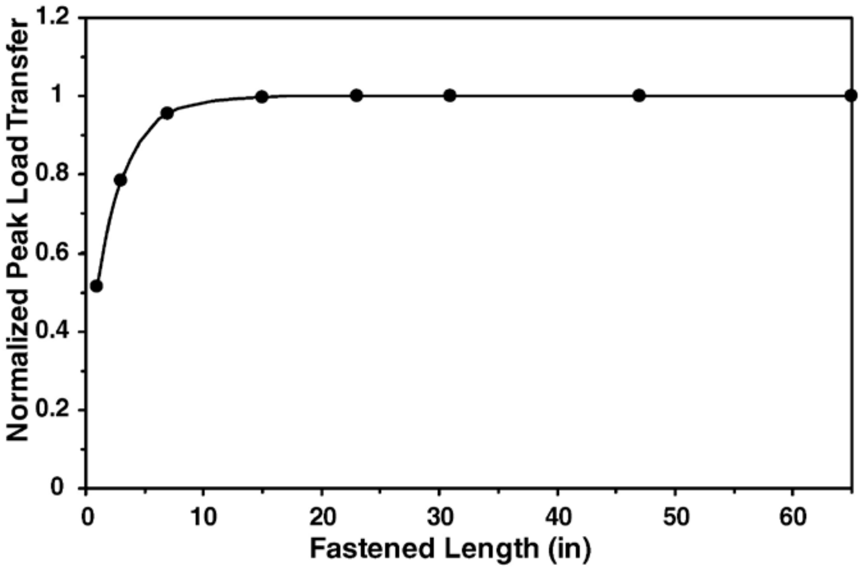


Fig. 28 Peak fastener-load transfer as a function of fastened length.

Galvanic Corrosion Considerations

- Cathode + electrolyte + anode = galvanic corrosion
- Carbon fiber is not be compatible with certain metals such as aluminum
- Lightning and static electricity protection material may also cause galvanic corrosion
  - Some of these newer materials have not been thoroughly tested for galvanic corrosion
  - Even when data is available, OEM may not share the data

Pictures showing the effects of various coatings on galvanic corrosion of aluminum and steel bolts after more than 1,000 hours of salt spray testing.

SOURCE: Nedschroef and Composites World Magazine

Fresh versus Expired Prepreg

- Two panels were made from Cytec Cycom 5320-1 T650 3k-PW prepreg

Panel made from fresh prepreg
No void is visible on the panel surface

Panel made from expired (6-year old) prepreg
High void content is visible on the panel surface
(in addition, we had to use a very slow temp ramp up rate to cause the high void content)

Fresh versus Expired Prepreg

- Through-Transmission Ultrasonic (TTU) test parameters
- Same parameters were used for both panels

NDI TECHNICAL DATA					
Program:	Yeow's CSTA Work Shop		**Transfer Amount:**	N/A	
Panel Name:	Expired Prepreg Baseline		**NDI Process Spec:**	CP6121 Rev. 5	
Material Type:	Carbon Laminate		**Inspection Date**	7-11-2016	
EQUIPMENT					
UT Instrument Manufacturer:	NDT Automation	**Flaw Detector Manufacturer:**	NDT Automation	**Nozzle Size:**	0.25 in Dia.
UT Instrument Model:	NDT Squirter System	**Flaw Detector Model:**	NDT Automation	**Couplant:**	Clean water
SCAN PARAMETERS					
Scan Speed:	6 in/s	**Scan Index:**	0.04 in	**Scan Mode:**	TTU C-Scan
UT PARAMETERS					
Gain:	-2.0 dB	**Sound Velocity**	0.124 in/us	**Gate Type:**	Gate 1
Frequency:	5 MHz	**Damping:** **Low Pass:** **High Pass:**	545 Ohm 30 MHz .5 MHz	**Gate Width:**	0.921 in
Transducer:	Flat	**Voltage:**	250V	**Gate Level:**	Auto Float 71.86%
Range:	5.562 in	**Delay:**	2.491 in	**Gate Position:**	4.613 in

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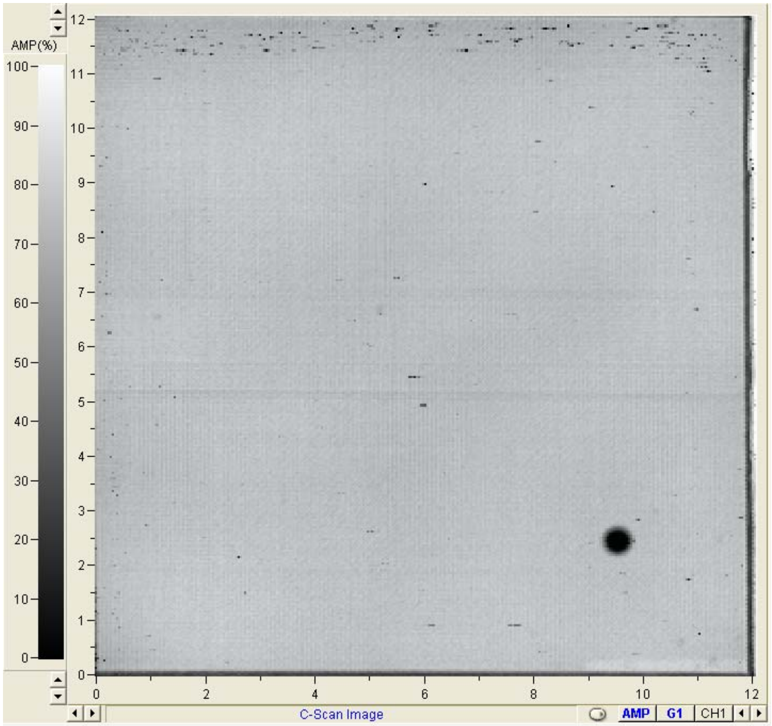
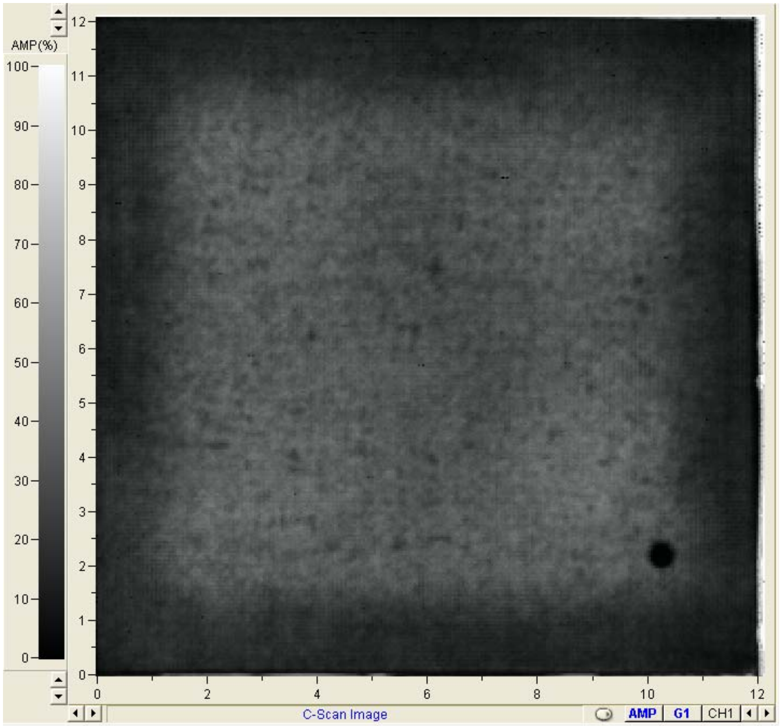
Scans Done by NIAR UT Level II: Brian Matzen

Report Prepared by NIAR UT Level II: Brian Matzen

Fresh versus Expired Prepreg



Fresh Prepreg Panel
Low void content = low attenuation



Expired Prepreg Panel
High void content = high attenuation

Scans Done by NIAR UT Level II: Brian Matzen
Report Prepared by NIAR UT Level II: Brian Matzen

Lightning strike, paint thickness effects
(This slide was provided by Mr. Brock Strunk, Epic Aircraft, LLC)

10 mils thick paint

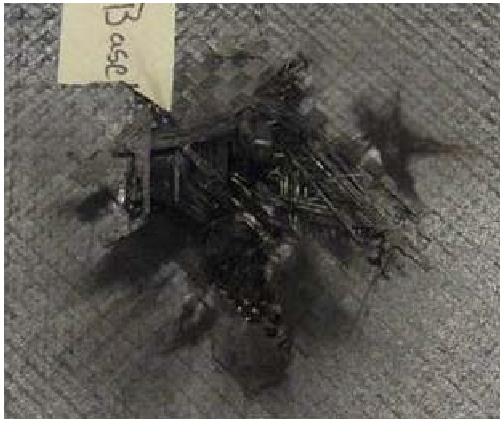
Front side

No damage on back side

The two panels are identical
The only difference was the paint thickness

20 mils thick paint

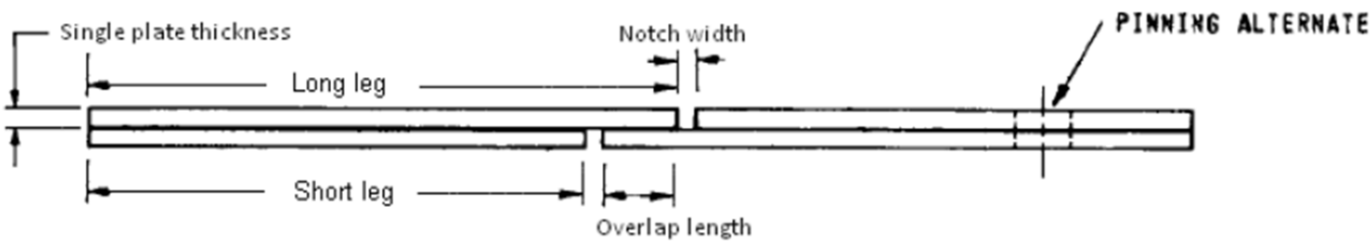
Front side



Back side punctured

Surface Preparation Effects

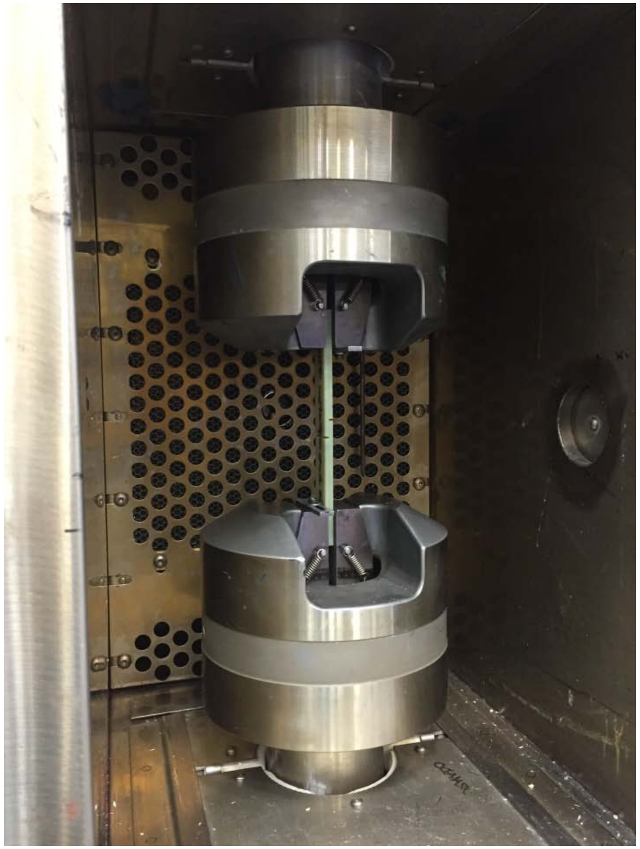
- baseline / control: sanded and acetone cleaned
- surface moisture: one adherent was wiped with wet cloth (also reminiscent of cocuring phenolic with epoxy)
- partially cleaned prior to bonding: both adherents were sanded but only one was cleaned with acetone
- contamination from peel-ply: peel-ply was left in the bondline.
- contamination from release agent: lightly wiped with Frekote 44NC

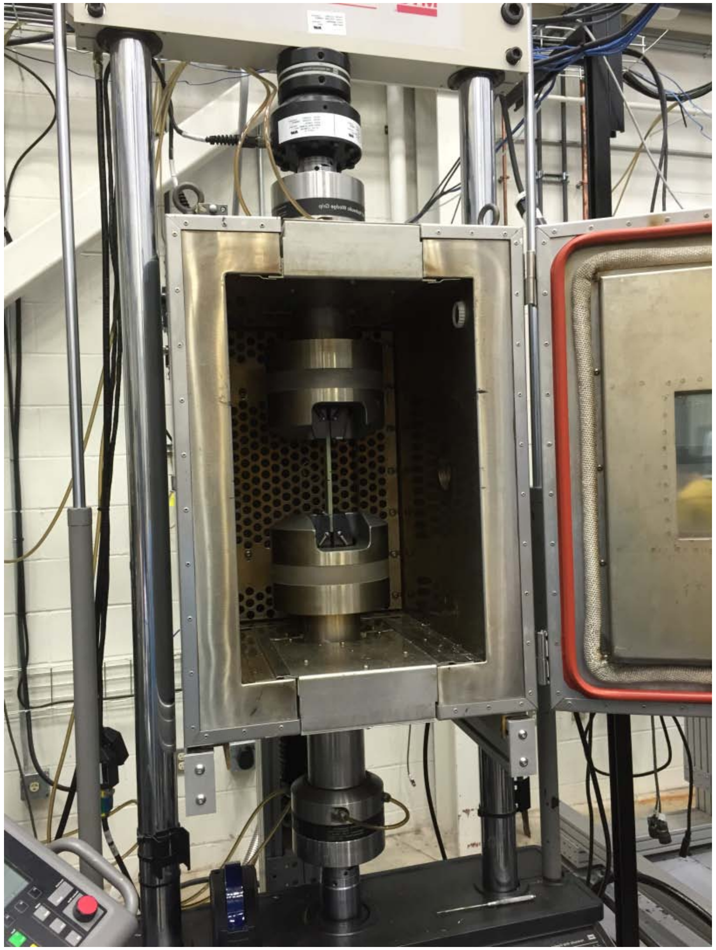


ASTM D3165 Lap Shear Test Method

Surface Preparation Effects

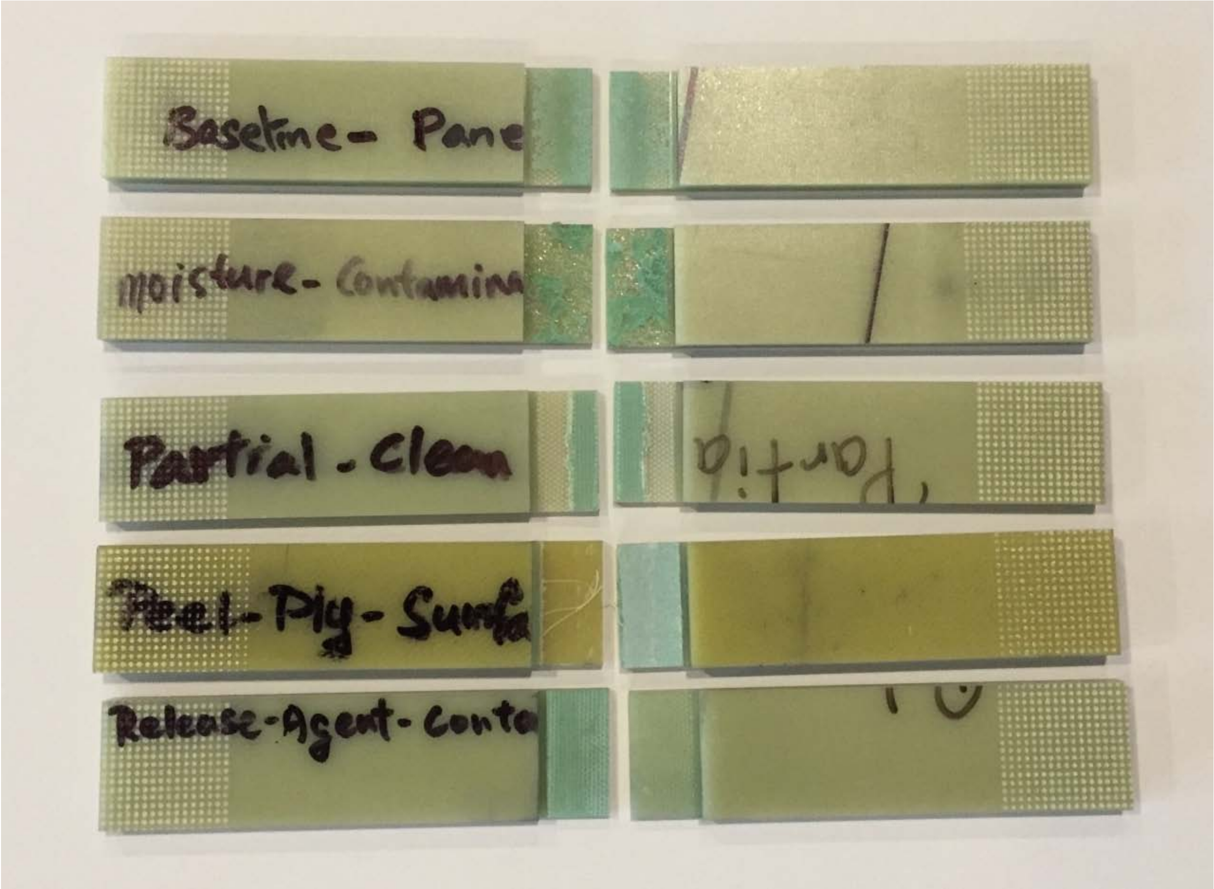
ASTM D 3165 Test setup





Surface Preparation Effects

- Pictures showing failure modes



Surface Preparation Effects

	Strength (ksi)	Coefficient of Variation (%)
Baseline	3.770	2.73
Surface moisture	0.081	125.28
Partially cleaned prior to bonding	2.910	1.28
Contamination from peel-ply	2.635	1.39
Contamination from release agent	1.998	25.60

- All forms of contamination caused reduction in lap shear strength
- Surface moisture had the most severe degration
  - This is not an unrealistic case since some companies are using water-based cleaners
  - Parts should be dried in the oven prior to bonding

Other Considerations

- Film adhesive and prepreg cocure incompatibility
  - Certain materials such as epoxy film adhesive and phenolic prepreg cannot be cocured together.
  - The curing process should be compatible.
  - As a general rule of thumb, we like to have the film adhesive reach minimum viscosity and gel before the prepreg, but microscopy evaluation of the bondline and mechanical tests are usually required

Suggestions and Questions?

- Some of the actual panels and specimens described in this presentation at here – please feel free to review them during the break