CACRC Process Parameters Investigation

Presented by:

Royal Lovingfoss

NIAR – Wichita State University

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CACRC Process Parameters Investigation

- **Principal Investigators & Researchers**

  John Tomblin Ph.D.

  Lamia Salah Ph.D.

  Royal Lovingfoss

  Ruchira Walimunige

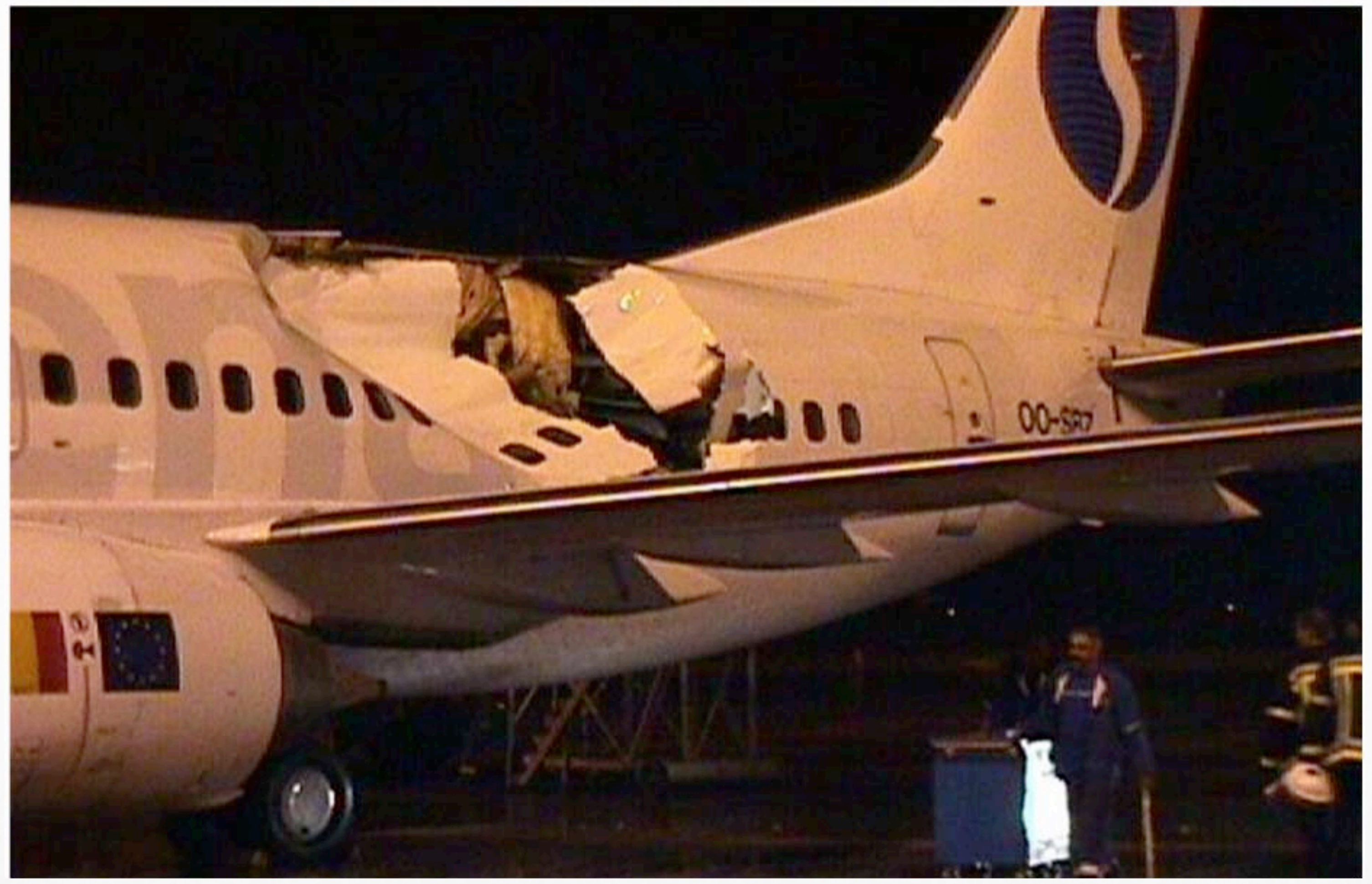
  Chathuranga Kuruppuarachchige

- **FAA Technical Monitor**

  Lynn Pham

Introduction

- Major Technological Advances using Composite Materials in the last 50 years (composite materials used for the first time in wing and fuselage load bearing structures)
- Durability, repairability, and maintainability are key elements in the continued airworthiness
- Challenges associated with composite repair and supportability of composite structures are of particular interest and must be addressed during the design phase



In-Service Damage, Courtesy Eric Chesmar, UAL

Research Objectives

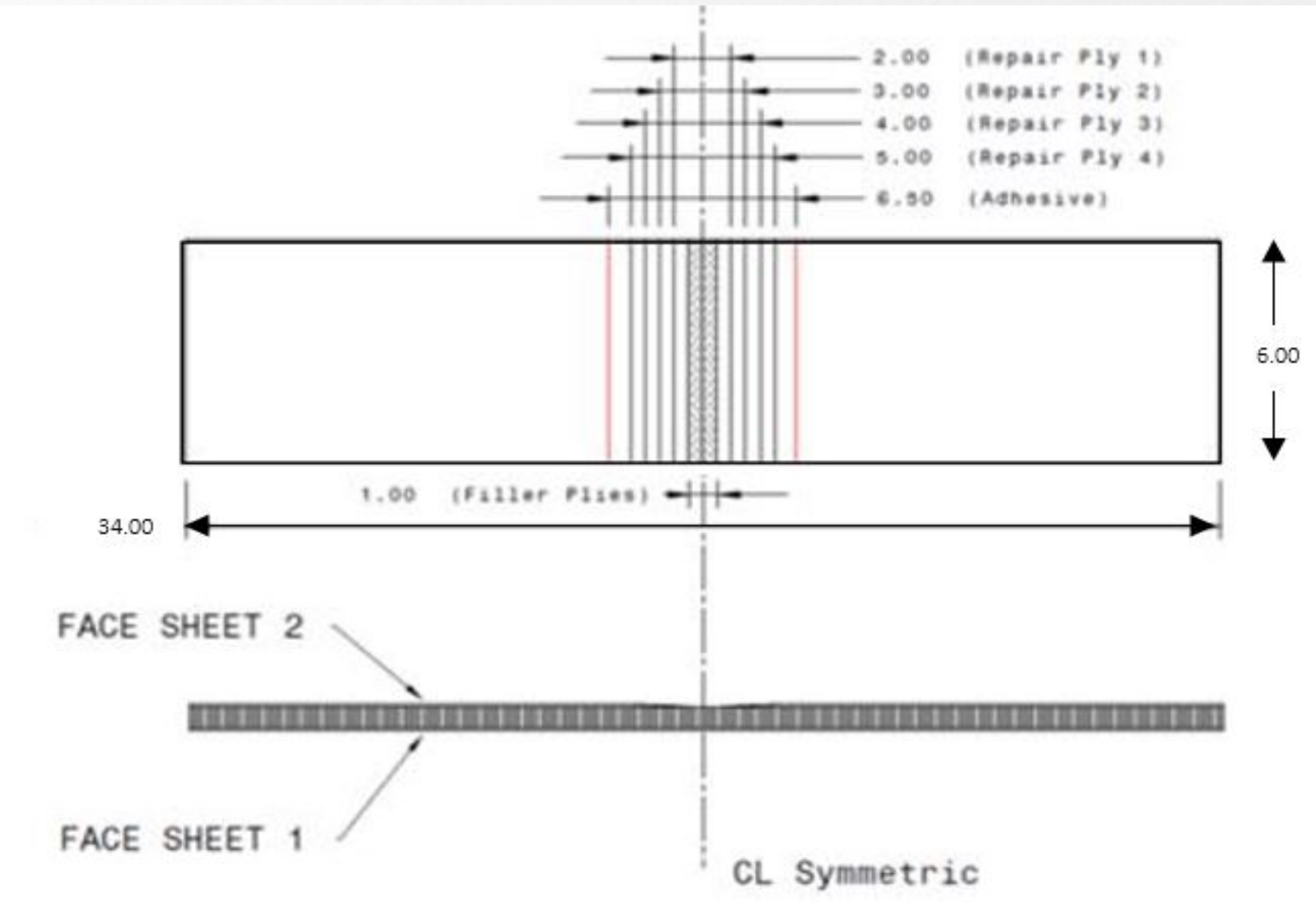
- To perform detailed post-test analysis of phase I repairs, identify critical process parameters in the execution of bonded repairs.
- Improved process checklists, post-test analysis of repaired elements, videos showing repair processing mistakes and the effects on structural performance.
- Defective repairs resulting in weak/poor bonds were created based on the lessons learned from phase I.
- The same substrate and repair materials used for the round robin exercise (phase I) were used for the study but with smaller repair elements.
- Factors such as material out-time, bagging scheme, incorrect resin ratios, pre-bond moisture resulting from minimal or no drying were used to create poor or weak bonds as found in phase I.

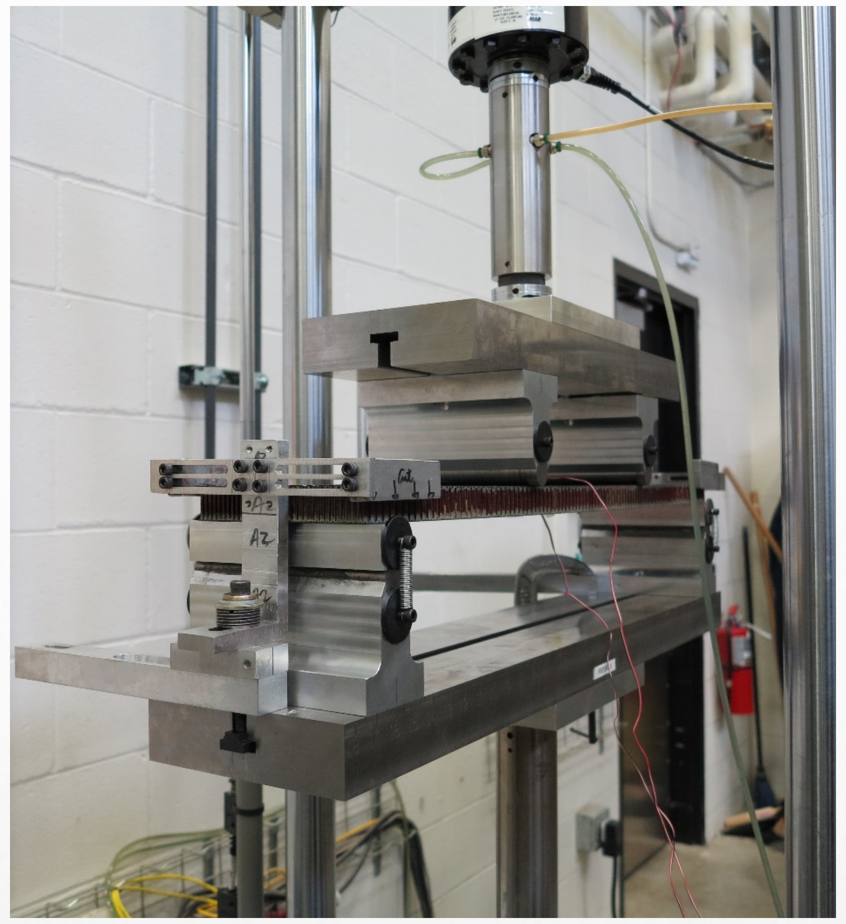
In Service Experience

Lessons Learned:

- Outstanding performance where reliable processes were used
- Adhesion failures are caused by deficient processes (prebond contamination, poor surface preparation, inadequate cure parameters that inhibit the formation of strong chemical bonds)
- Cohesion Failures are caused by poor design (thermal residual stresses, stiffness mismatch between adherends, poor material selection, inadequate repair overlap, porous bondlines)
- NDI methods cannot guarantee absolute bond integrity, rigorous bond quality management, repair definition and process execution is essential to achieve repeatable and structurally reliable bonded repairs

Research Approach/ Methodology





Sandwich Repair Element Configuration Representative of production hardware/ materials and processes

- Small beams, 6” x 34” with the repair tested in compression
- 1” width gap to maintain a W/G>4 (6” used in this study)
- 1” thick core, 3/16” core cell size, 4-ply facesheets
- No core restoration, facesheet repair on FS2 (top)
- Rectangular repair area (6”X6”)

Parent Material:
T300/934 3K PW with FM 377S adhesive (Solvay)

Repair Materials:
CACRC repair 1 (Prepreg): Hexcel M20 PW (250^{o}F cure) with EA9695 adhesive film (Henkel)
CACRC repair 2 (Wet Layup): Hexcel G904 D1070 TCT (210^{o}F cure) with Epocast 52A/B resin (Huntsman)

Repair Procedures

- Two Repair methods are conducted with several variation of process parameters
- CACRC R1, a prepreg repair using CACRC approved repair materials
- CACRC R2, a wet lay-up repair using CACRC approved repair materials

Repair Process Parameters

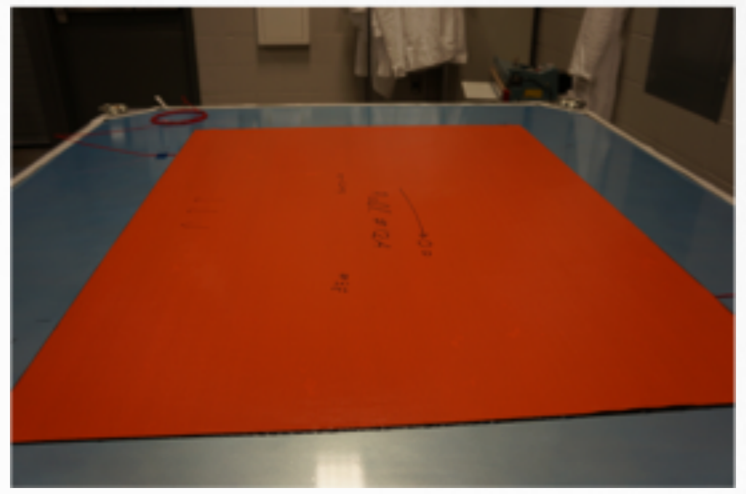
OP - Optimum Process
UE - Uncontrolled Environment
VB - Vertical Bleeding
LV - Low Vacuum
UC - Under Cure
AM - Adhesive Maximum Out time
OC - Over Cure
EA - Expired Adhesive
EM - Expired Material
NB - No Bleed
VLV - Very Low Vacuum

Test Matrix

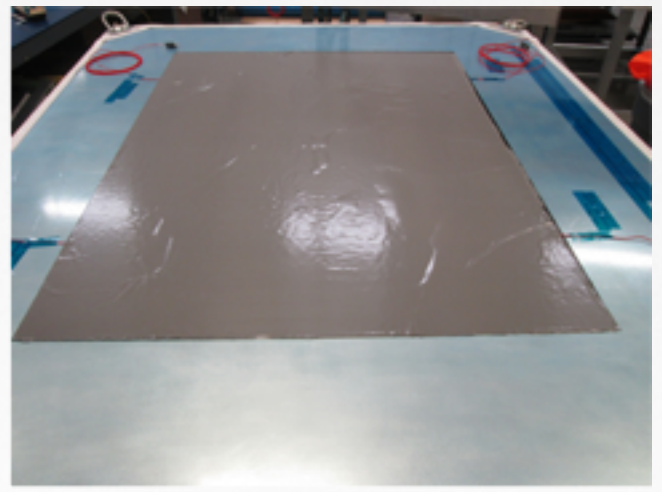
Repair Station	Element Configuration Variables	Repair Material	Loading Mode	Process Deviation	Static RTA	Static ETW	Fatigue ETW
NIAR - NCAT	Pristine/ Undamaged	-	Compression	Optimum Process [OP]	3	3	3
		CACRC-R1			3	3	3
		CACRC-R2			3	3	3
NIAR - NCAT	Defective Repairs (Poor/ Weak Bonds)	CACRC-R1 (Prepreg)	Compression	Uncontrolled Environment 1 month [UE]		3	3
				Vertical Bleed [VB]		3	3
				Low Vacuum [LV]		3	3
				Very Low Vacuum [VLV]		3	3
				Wrong Cure Cycle - Undercure [UC]		3	3
				Adhesive Maximum Out time [AM]		3	3
				Expired Adhesive [EA]		3	3
		CACRC-R2 (Wet Layup)	Compression	Uncontrolled Environment 1 month [UE]		3	3
				No Bleed [NB]		3	3
				Low Vacuum [LV]		3	3
				Wrong Cure Cycle - Overcure [OC]		3	3
				Expired Material [EM]		3	3
						Total	99

Parent Panel Manufacture

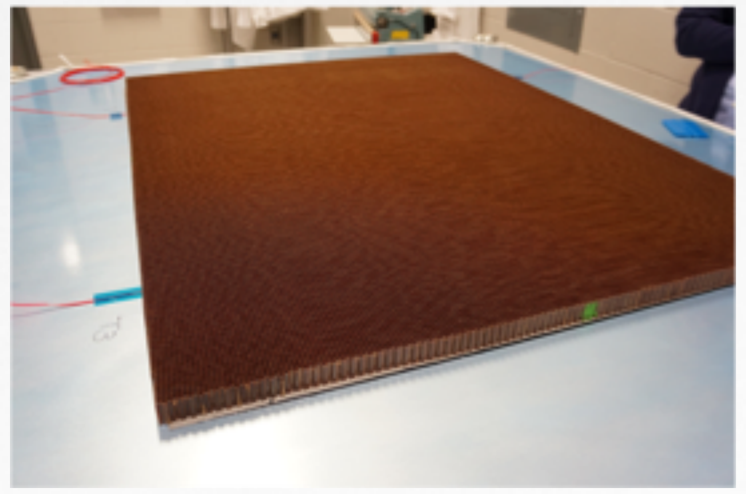
FS1 Layup



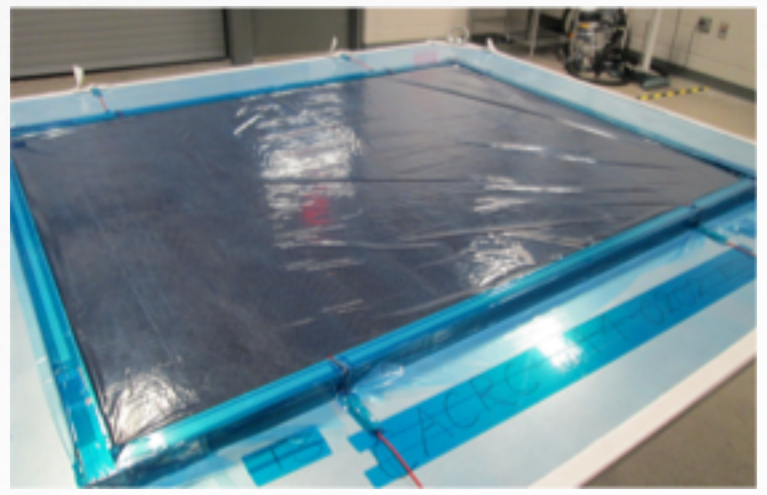
FS1 Adhesive



Uncured Assembly 1

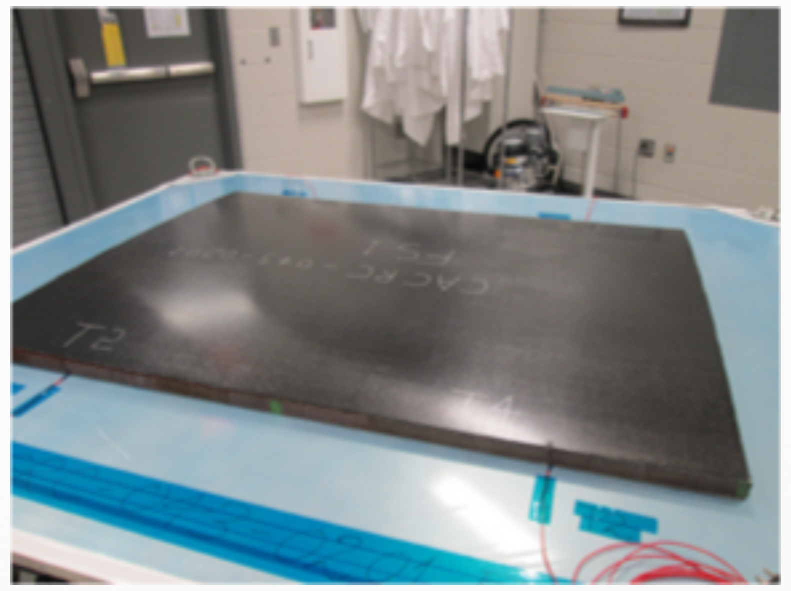


Bagging Assembly 1

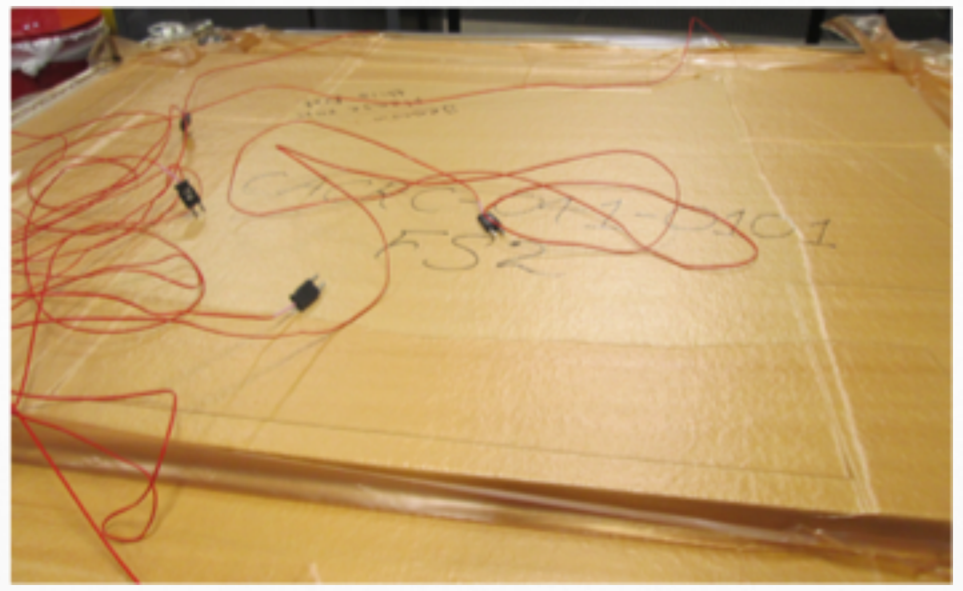


Assembly 1

Cured FS1 and Uncured FS2

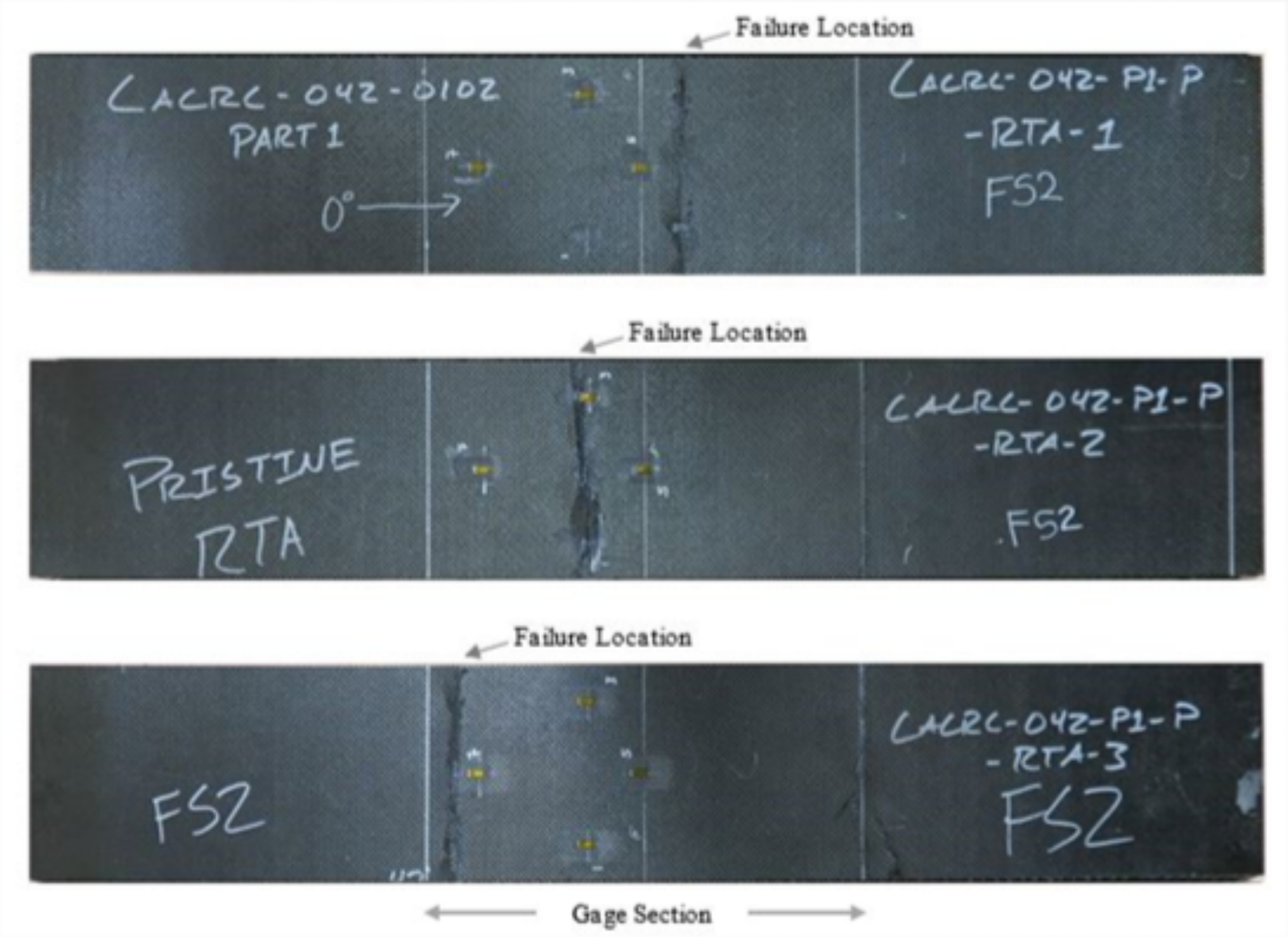


Final Assembly



Assembly 2

Repair Element Design Validation

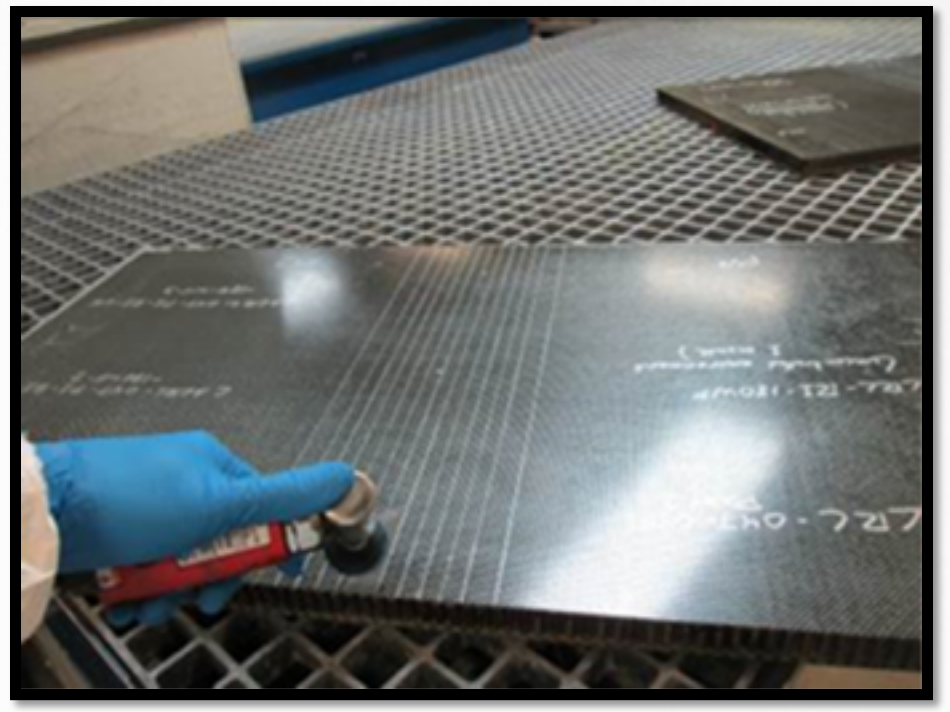


Failure Modes

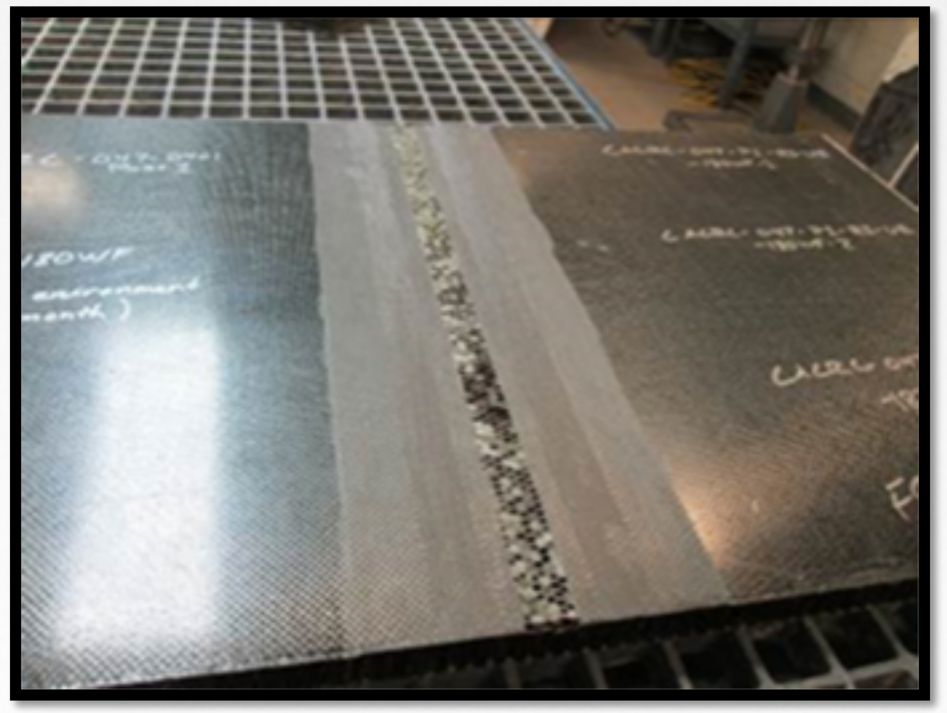
- Sandwich elements are instrumented using 7 strain gages
- Compression failures are observed for all three elements
- Average ultimate strain of 8350 microstrain
- A deflectometer is used to monitor bending deformation at centerline of the beam element
- ASTM D7249 (modified)

Prepreg Repair Procedure

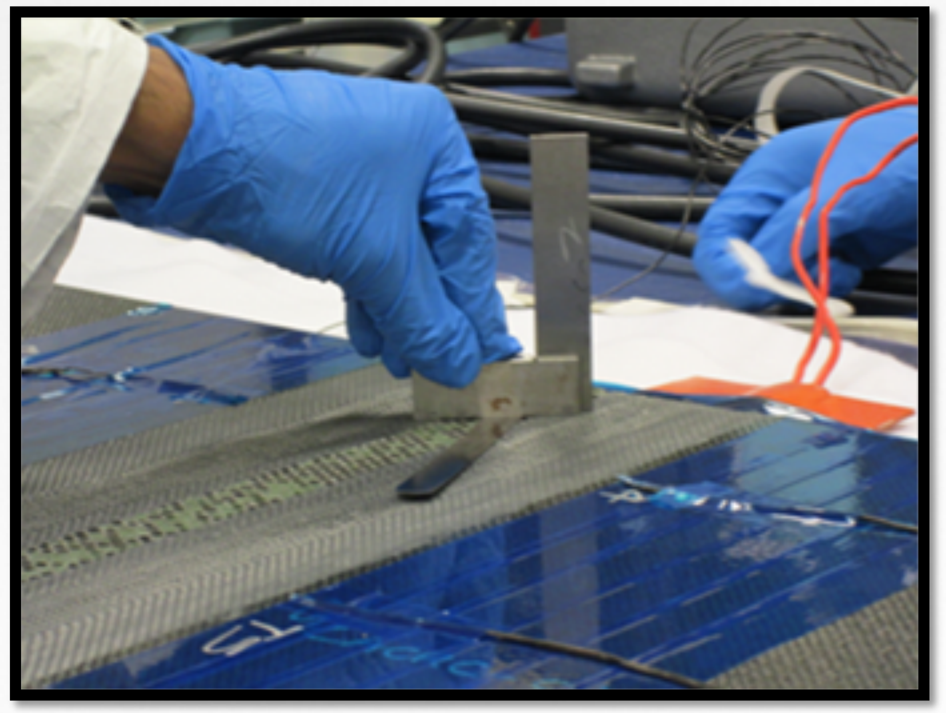
Scarf Lines



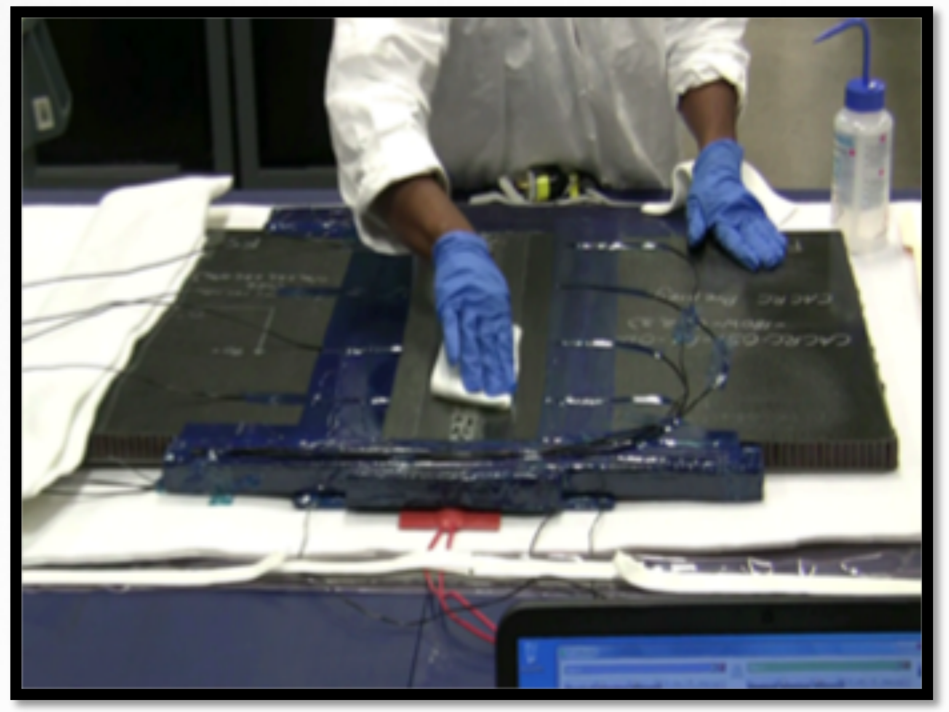
Scarf Sanding



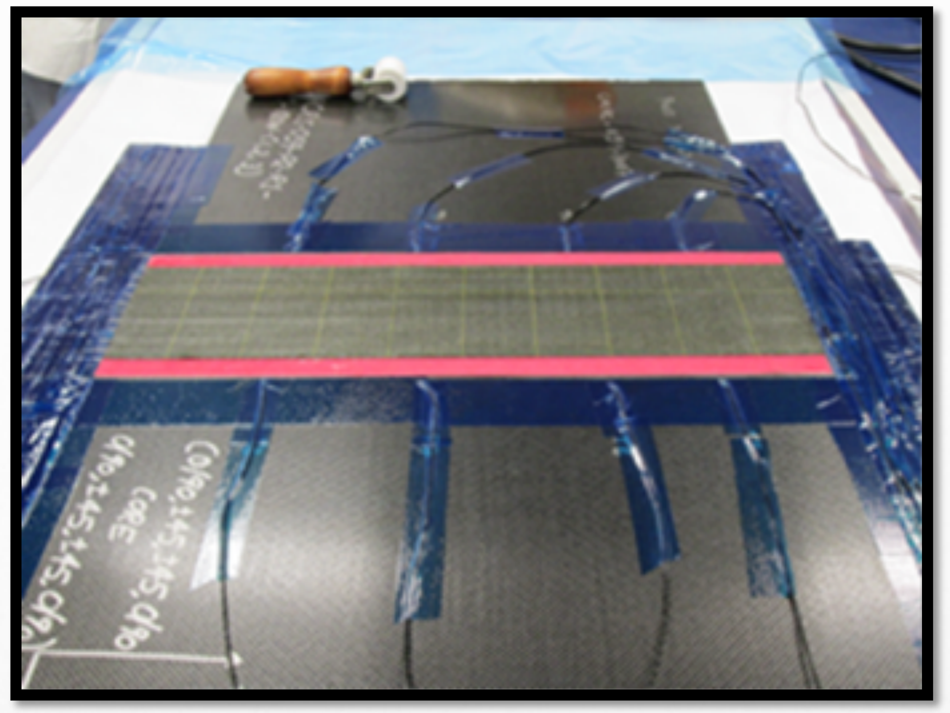
Filler Ply Determination



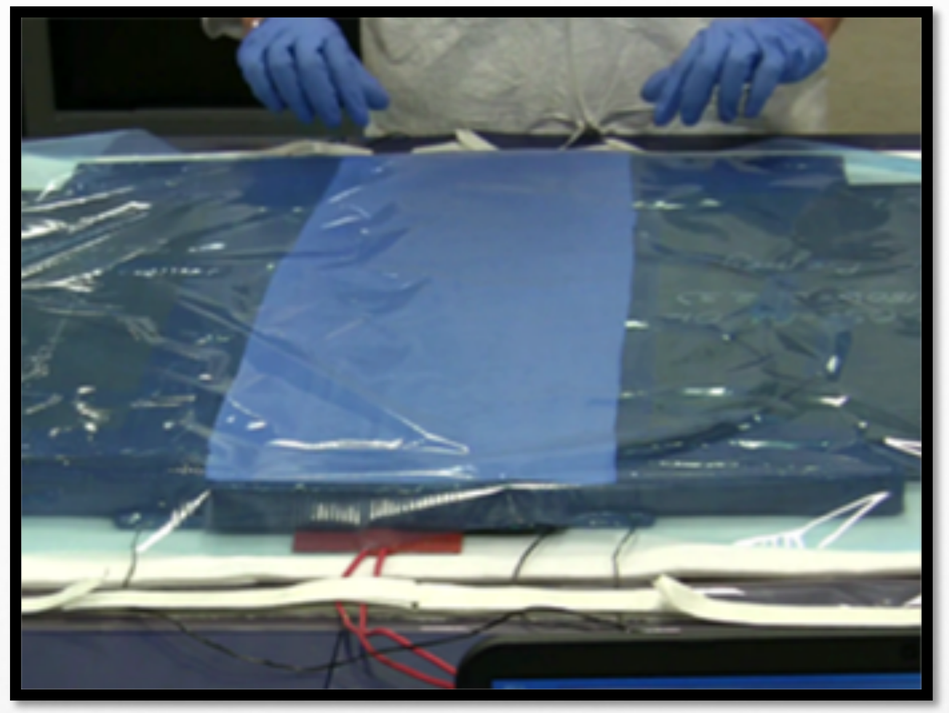
Final Cleaning



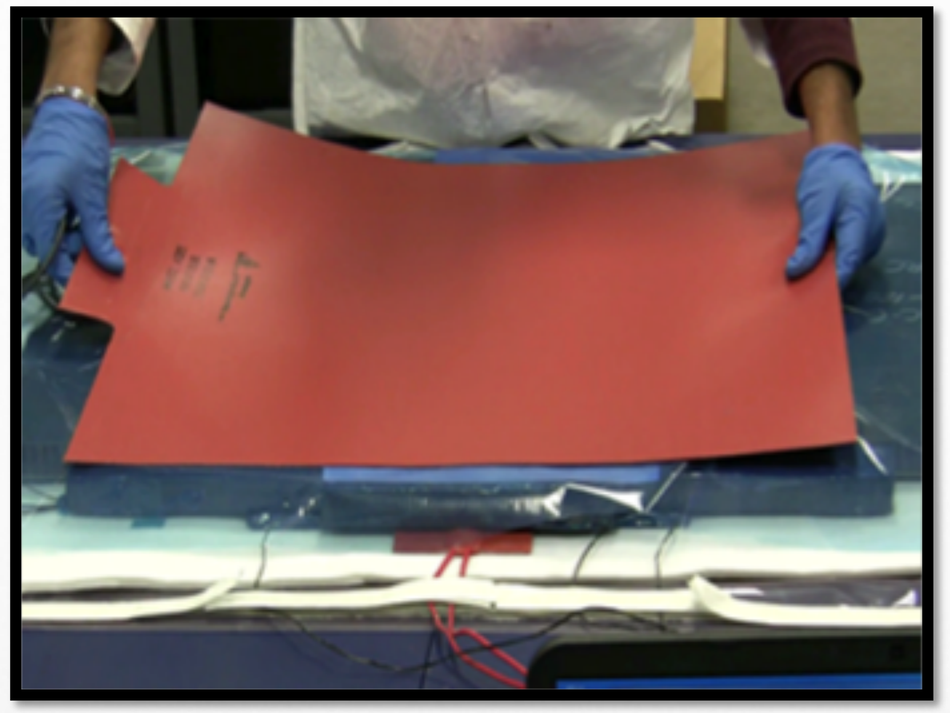
Repair Adhesive and Plies Application



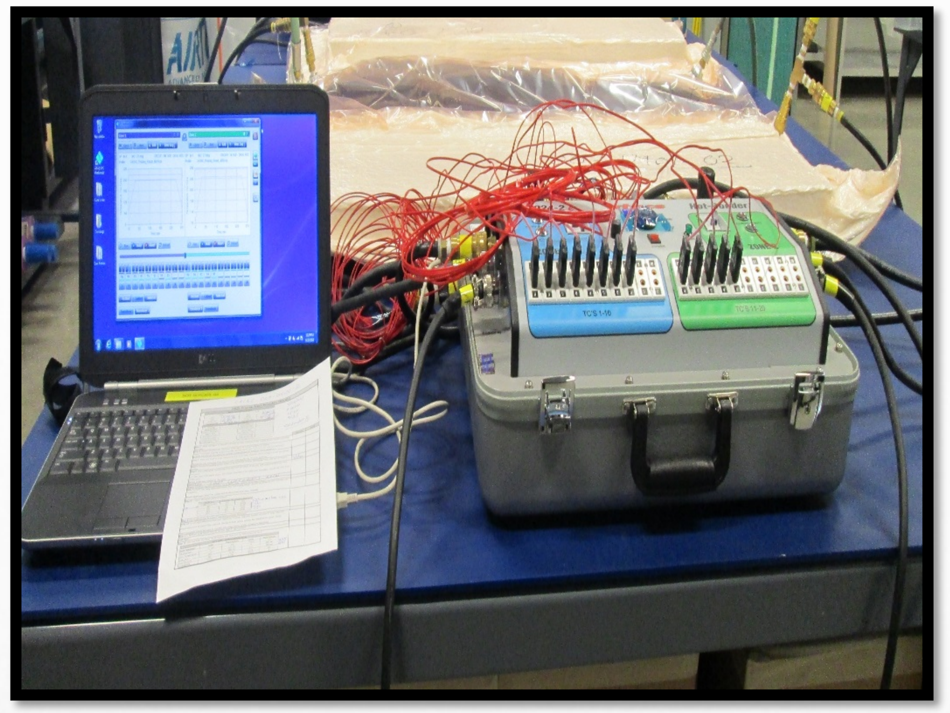
Bagging



Heat Blanket Application

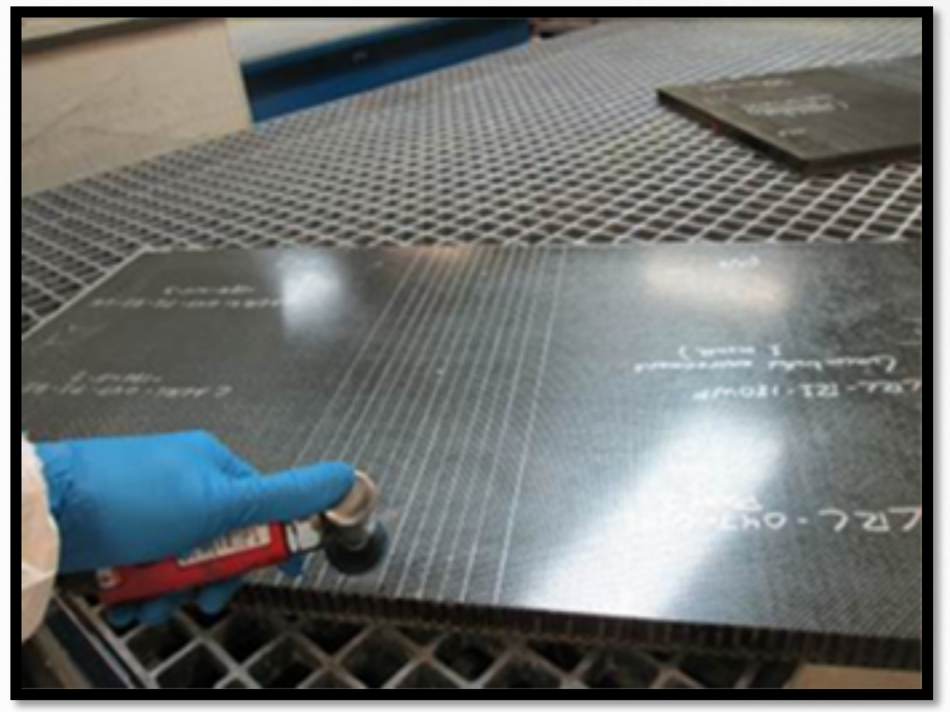


Repair Cure using Hot-Bonder Atacs – Model 8024-2e

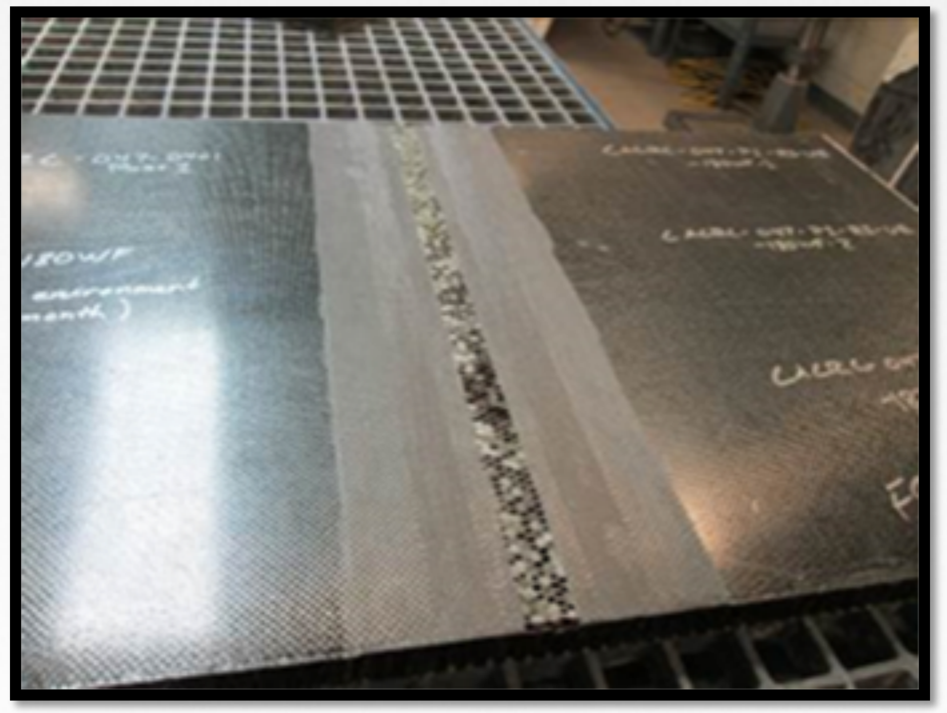


Wet Layup Repair Procedure

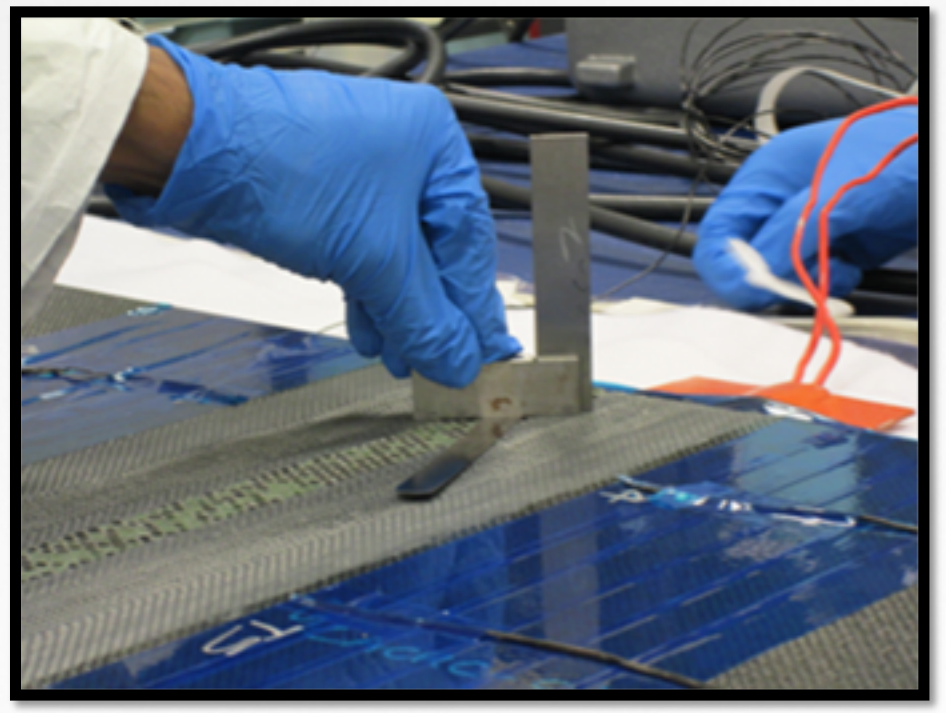
Scarf Lines



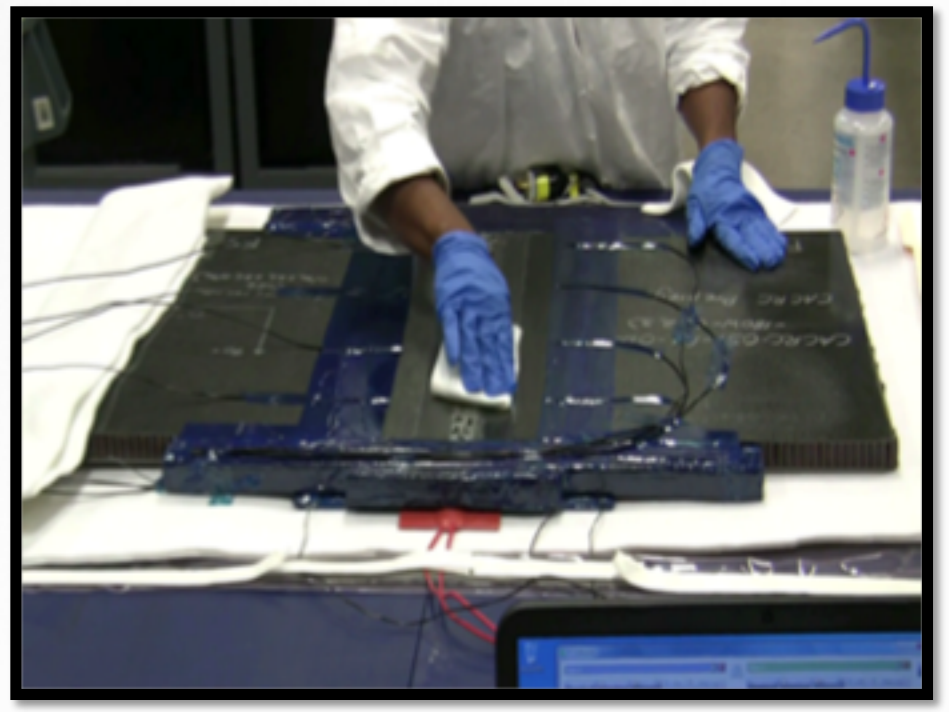
Scarf Sanding



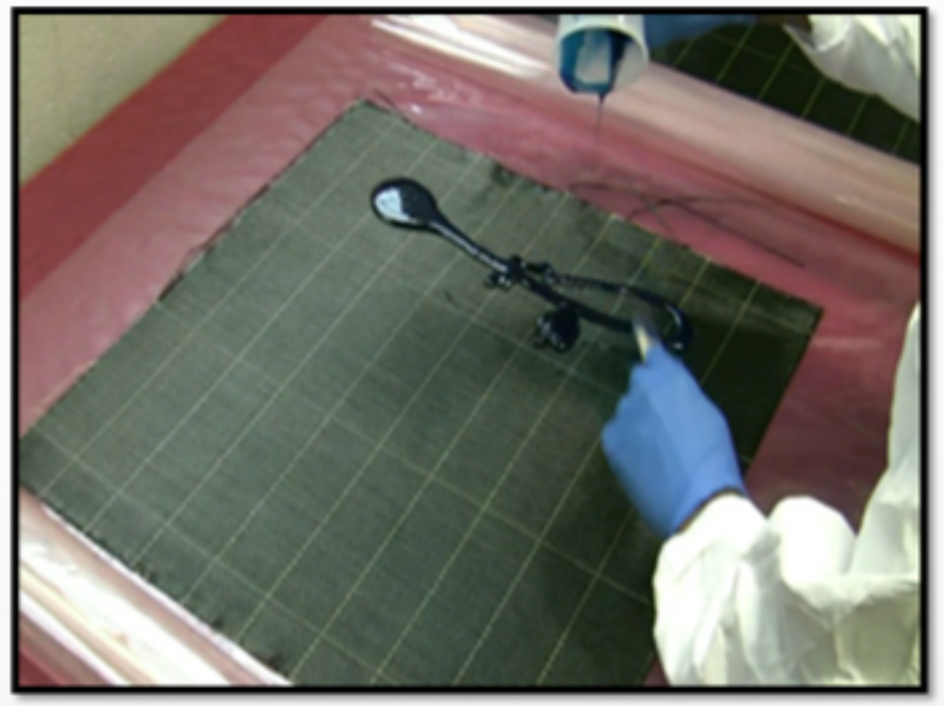
Filler Ply Determination



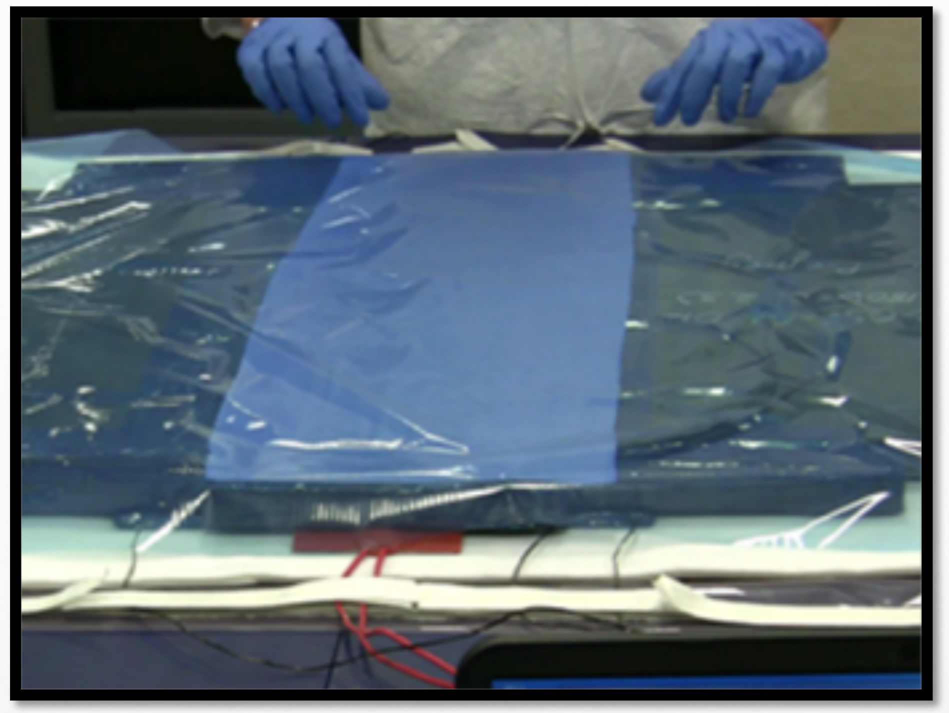
Final Cleaning



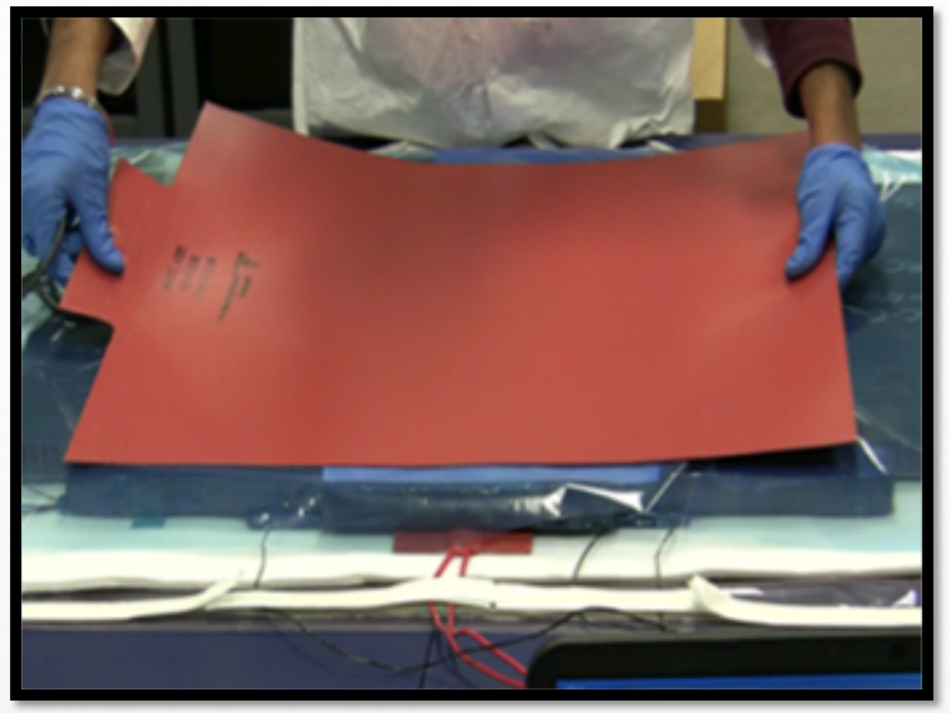
Resin Impregnation



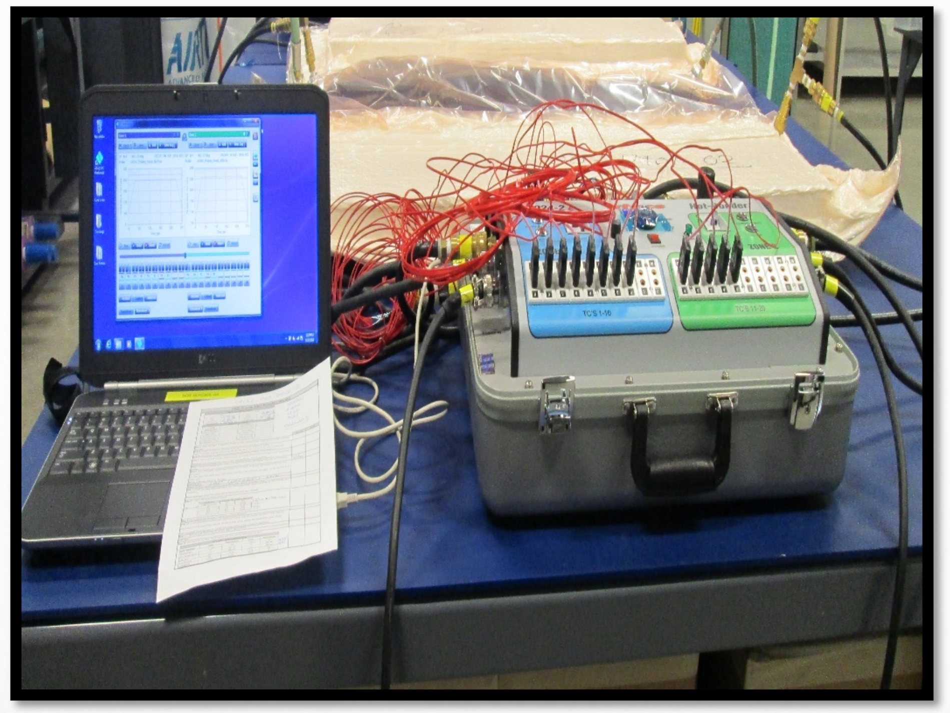
Bagging



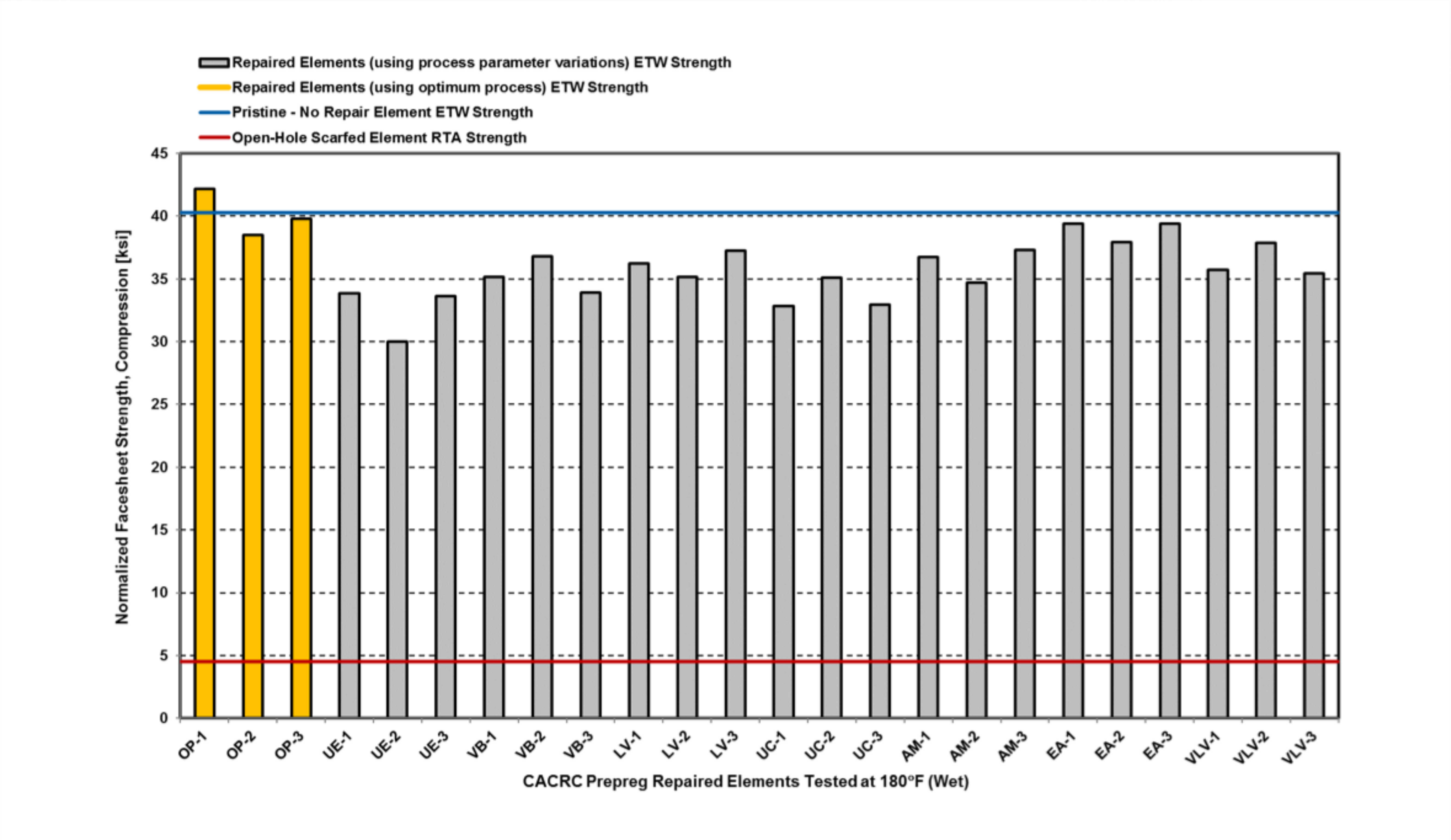
Heat Blanket Application



Repair Cure using Hot-Bonder Atacs – Model 8024-2e

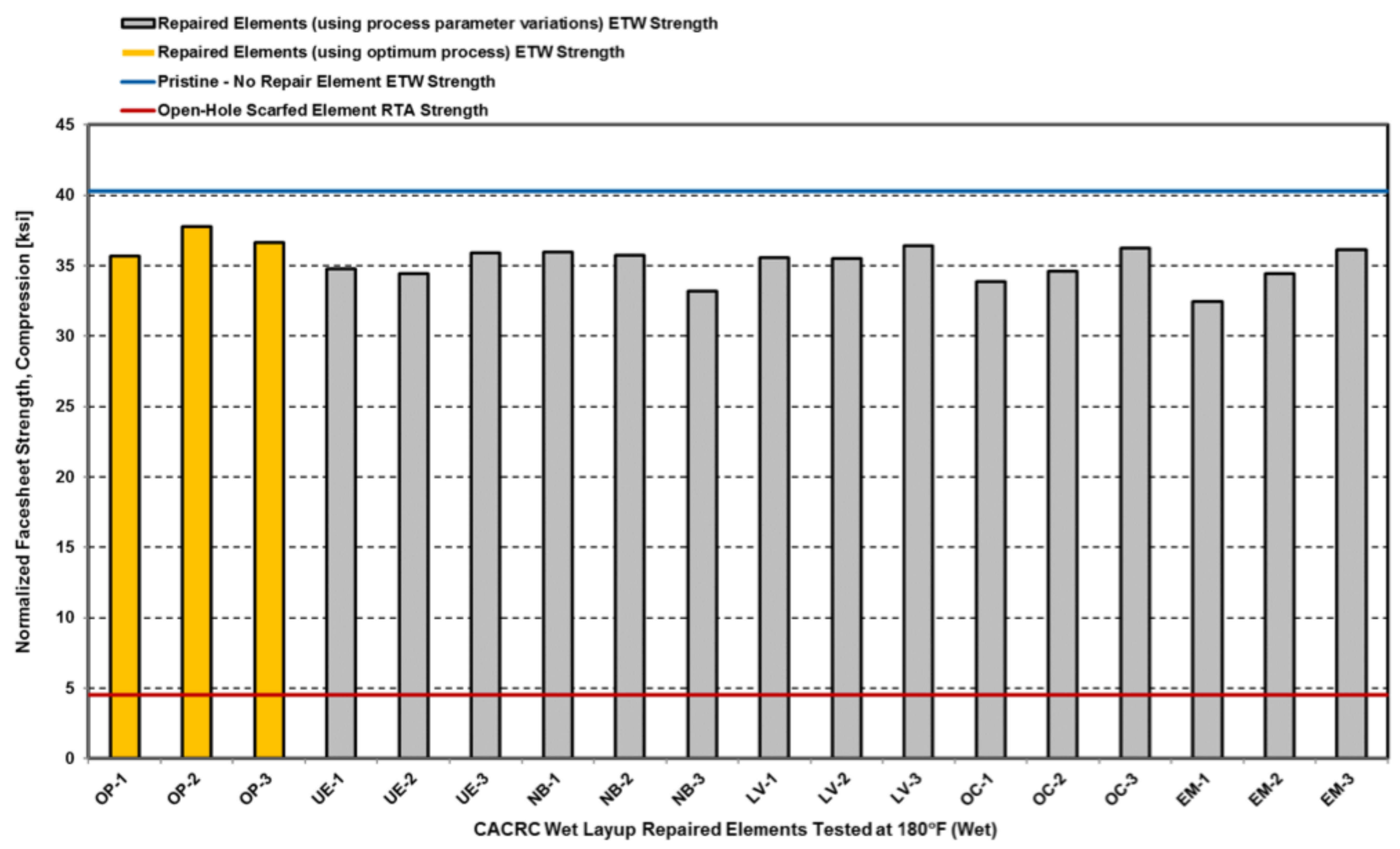


Results – Prepreg Repair



- 24 data points (instead of 48), ETW Fatigue results not presented
- Optimum repair strength: Avg=40.2 ksi, Min=38.5 ksi, Max=42.2 ksi
- Repair process parameter variations strengths: Avg=35.6 ksi, Min=30.0 ksi, Max=39.4 ksi

Results – Wet Layup Repair



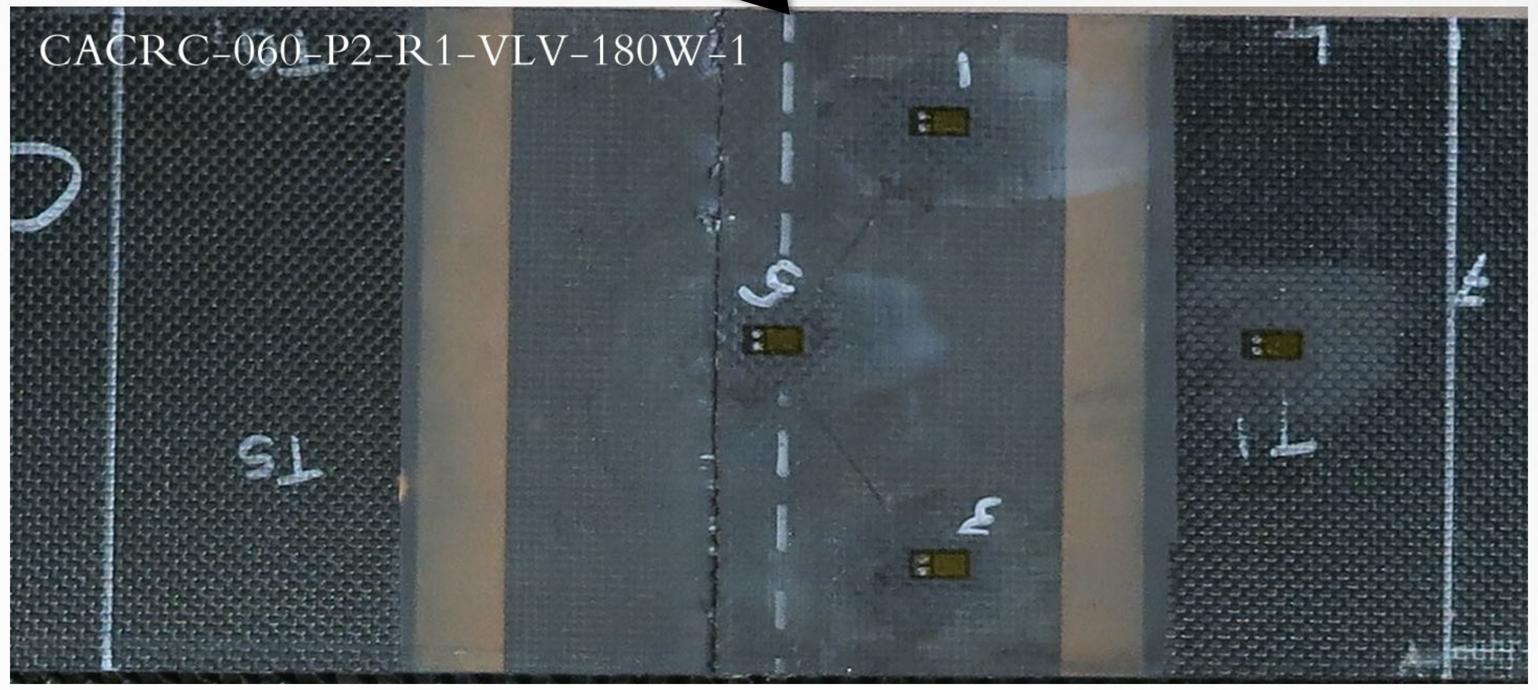
- 18 data points (instead of 36), ETW Fatigue results not presented
- Optimum repair strength: Avg=36.7 ksi, Min=35.7 ksi, Max=37.8 ksi
- Repair process parameter variations strengths: Avg=35.0 ksi, Min=32.4 ksi, Max=36.4 ksi

Prepreg Repair Failure Modes

All elements repaired with the CACRC prepreg yielded laminate compression failures within gage section (67% failed inside the repair, 33% failed outside the repair)

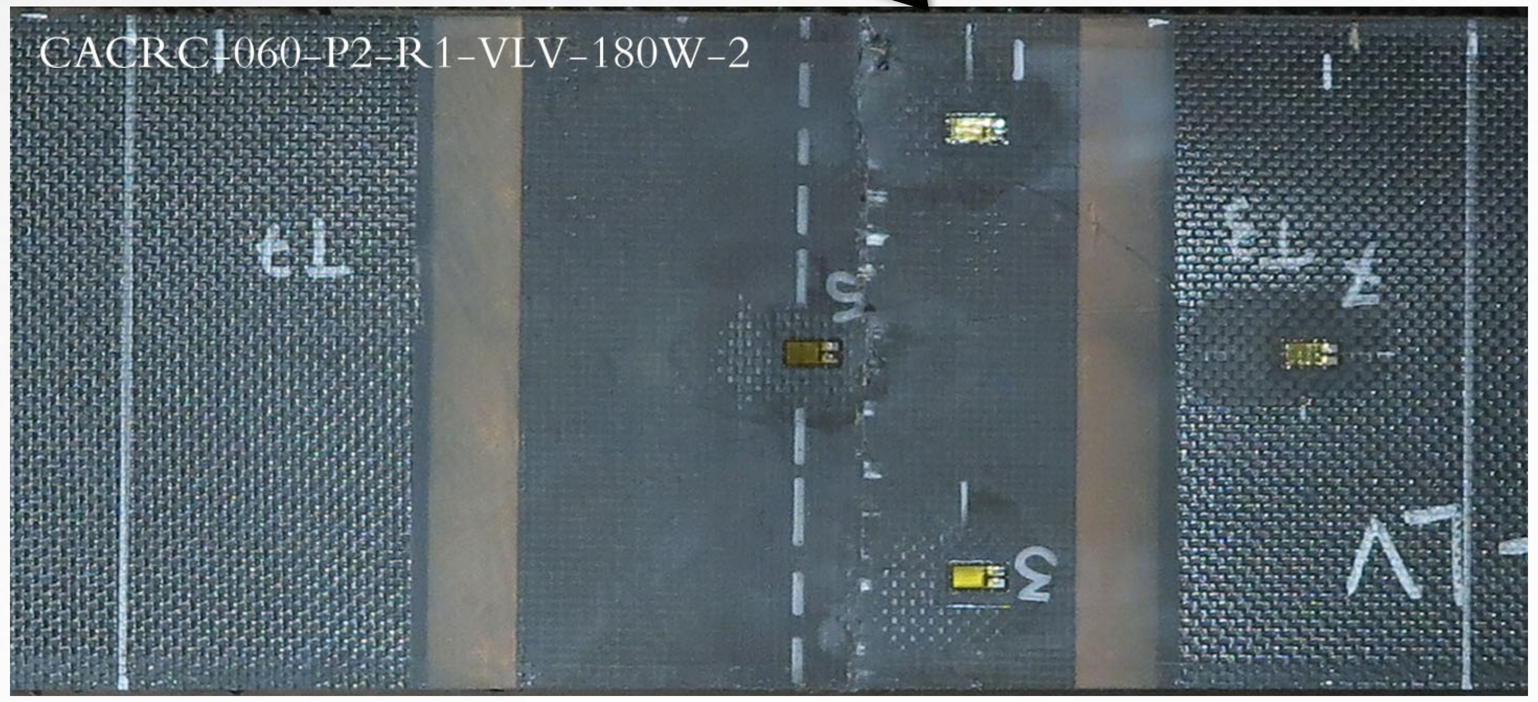
No adhesion failures, only facesheet failures

Failure Location



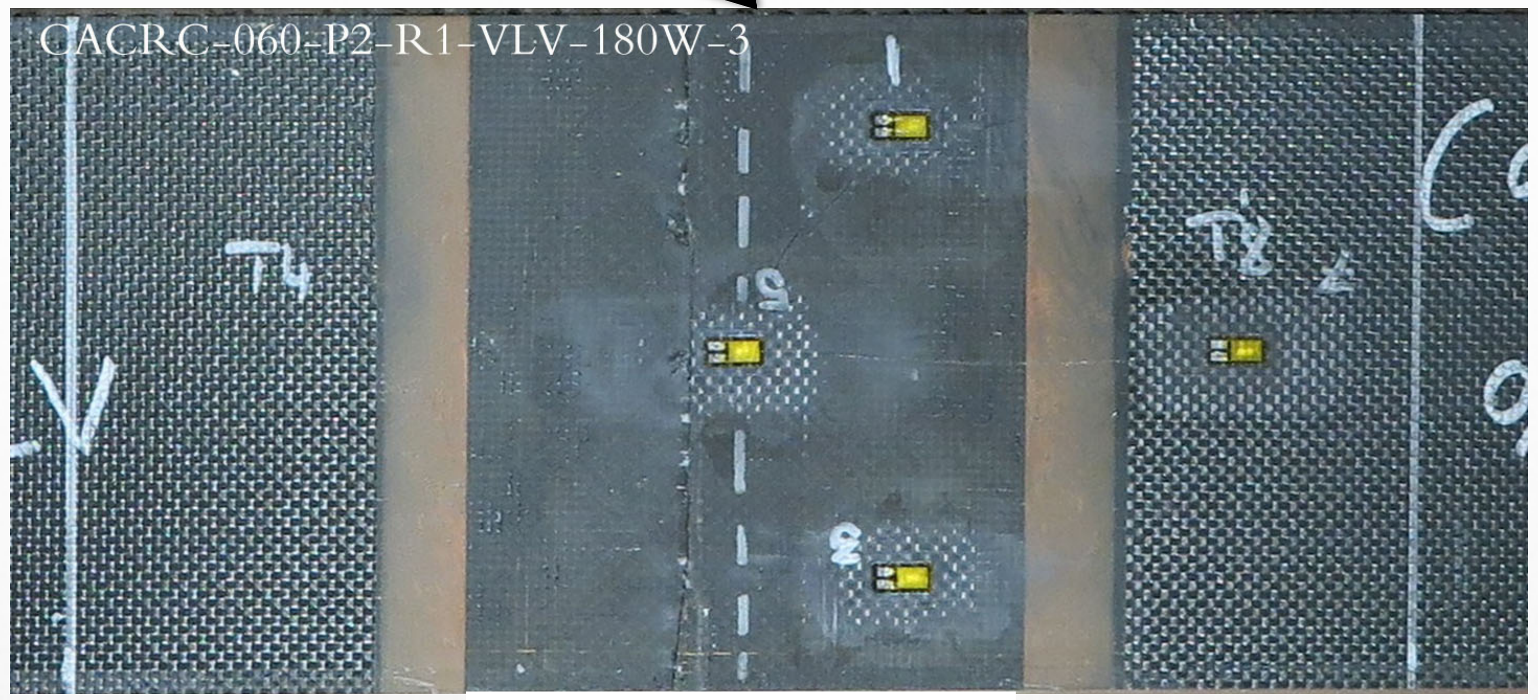
Gage Section

Failure Location



Gage Section

Failure Location



Gage Section

CECAM

NIAR Wichita State University National Institute for Aviation Research

JAMS

AMTAS Advanced Materials in Transport Aircraft Structures

WSU
Wichita State University

Wet Layup Repair Failure Modes

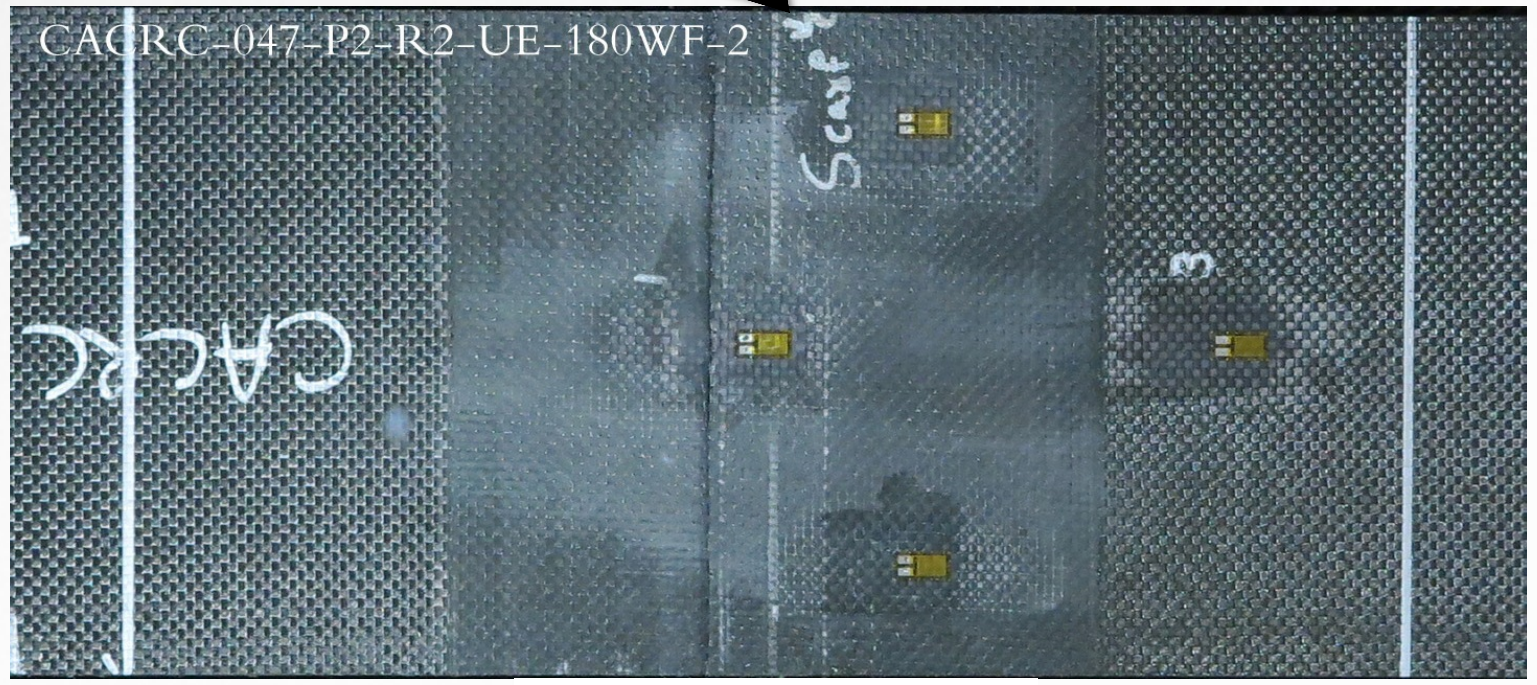
All elements repaired with the CACRC prepreg yielded laminate compression failures within gage section (67% failed inside the repair, 33% failed outside the repair)

Both adhesion failures and facesheet failures in some repairs

Failure Location

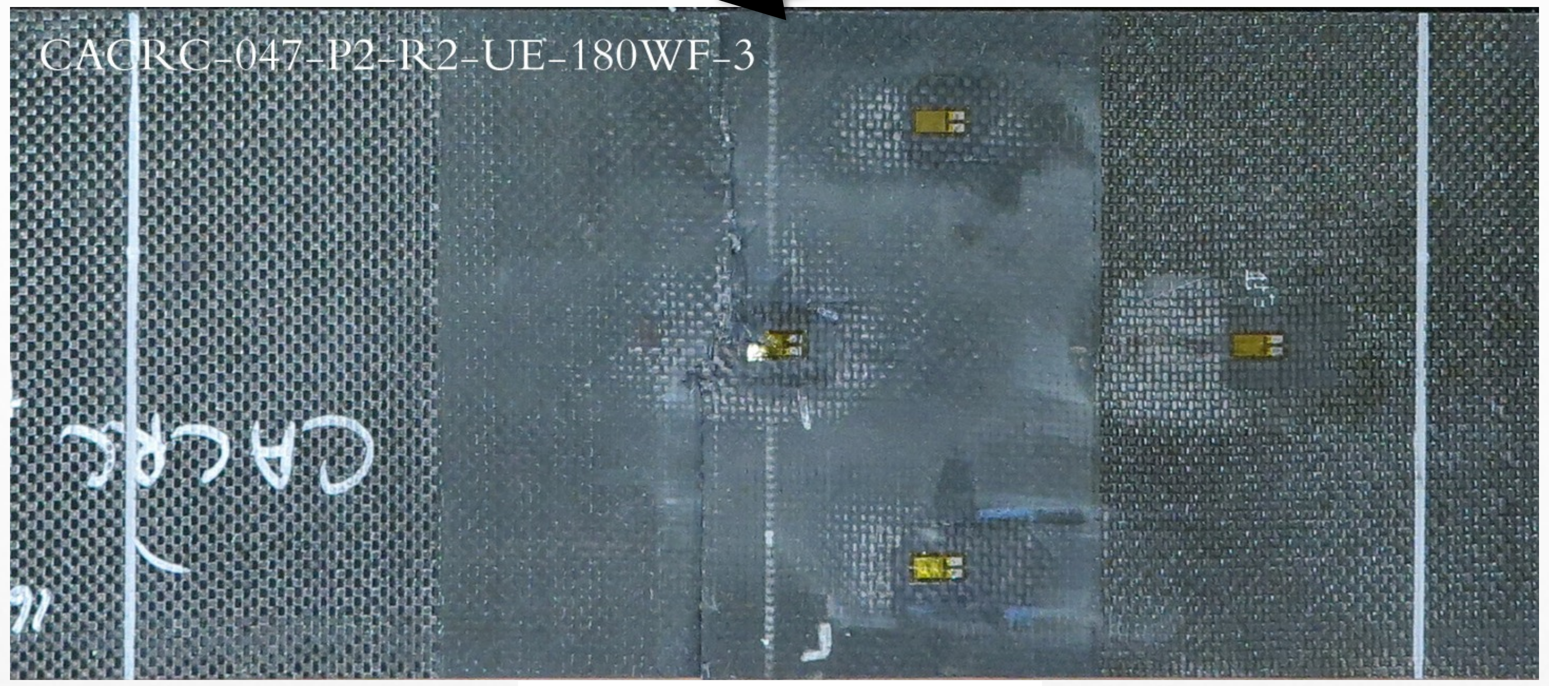
Gage Section

Failure Location



Gage Section

Failure Location



Gage Section

CECAM
NIAR Wichita State University National Institute for Aviation Research
JAMS
AMTAS

Post Test Analysis (In-Progress)

- Photomicrograph – Void content (phase II)
- DMA – Tg (phase II)
- Acid Digestion – Void content (phase II)

Some Key Lessons

- **Infrastructure for maintenance and supportability –** robust repair design and execution will yield strong durable bonded repairs
- **Altering process parameters –** lead to defective repairs, which results weak bonds
- Some repairs exhibit strong bonds, regardless of process parameter deviations
- Importance of repair process development, substantiation, and execution