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Guidelines for Characterization of Repair Materials

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JAMS 2019 Technical Review
May 22-23, 2019

Development of Repair Qualification Program

- Technical Monitor: Ahmet Oztekin
- NIAR Contacts: John Tomblin, Rachael Andrulonis, Royal Lovingfoss, Jeff Gilchrist

- Objectives
  - Primary objective: To develop a framework for the qualification of new and innovative material platforms for composite repair including guidelines and recommendations for their characterization, testing, design and utilization.
  - Secondary objective: To transition the test data and guidelines generated in this program into shared databases, such as CMH-17.

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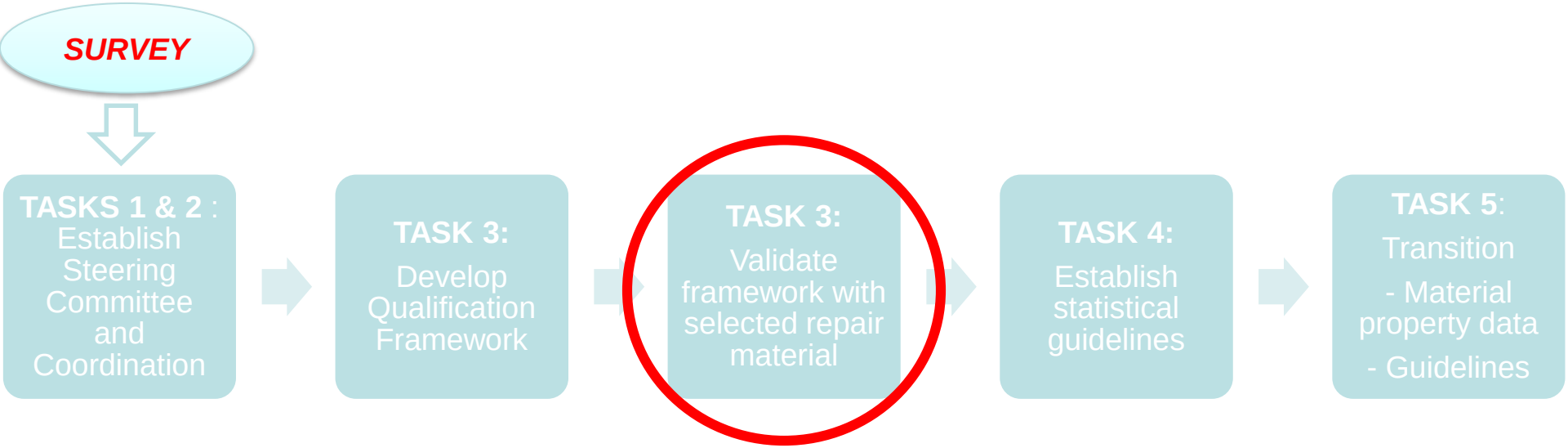
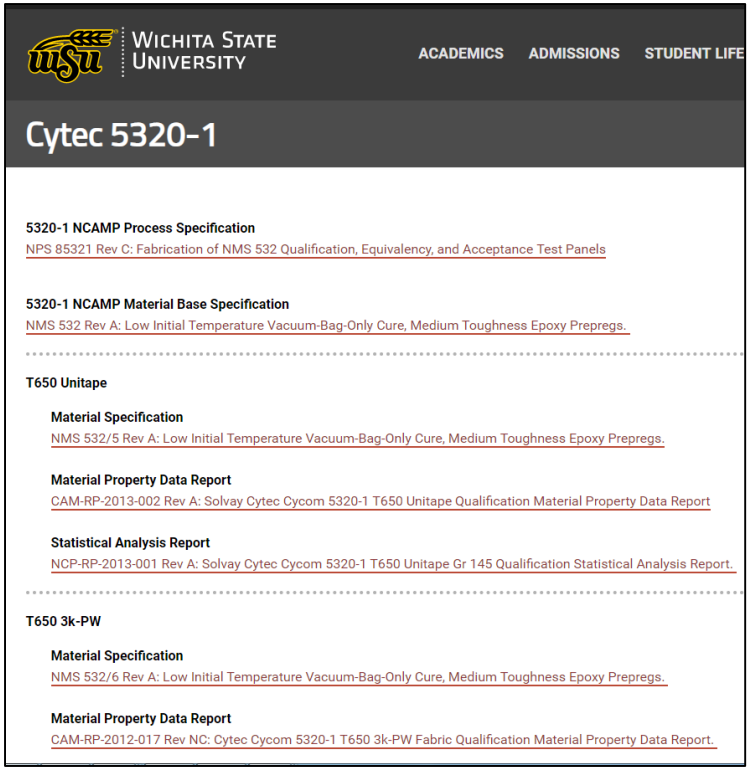
Technical Approach

- Develop a framework to advance repair materials into the aerospace industry.
- Utilize the experience and framework of the NCAMP composite program as an example of process sensitive material characterization.
- Assess the validity with equivalency testing.



Material Selection & Process Specifications

- Out-of-autoclave prepreg material
  - Solvay 5320-1 T650 3K PW prepreg
  - Originally qualified by NCAMP – reports published on NCAMP website and data included in CMH-17 Volume 2 Revision H
  - Equivalency and parent panels were fabricated to NCAMP process specification NPS 85321
  - Repair panels were repaired to NCAMP Process Specification NPS 80530R using Solvay FM 300-2M 0.06 psf Film Adhesive



https://www.wichita.edu/research/NIAR/Research/cytec5320-1.php

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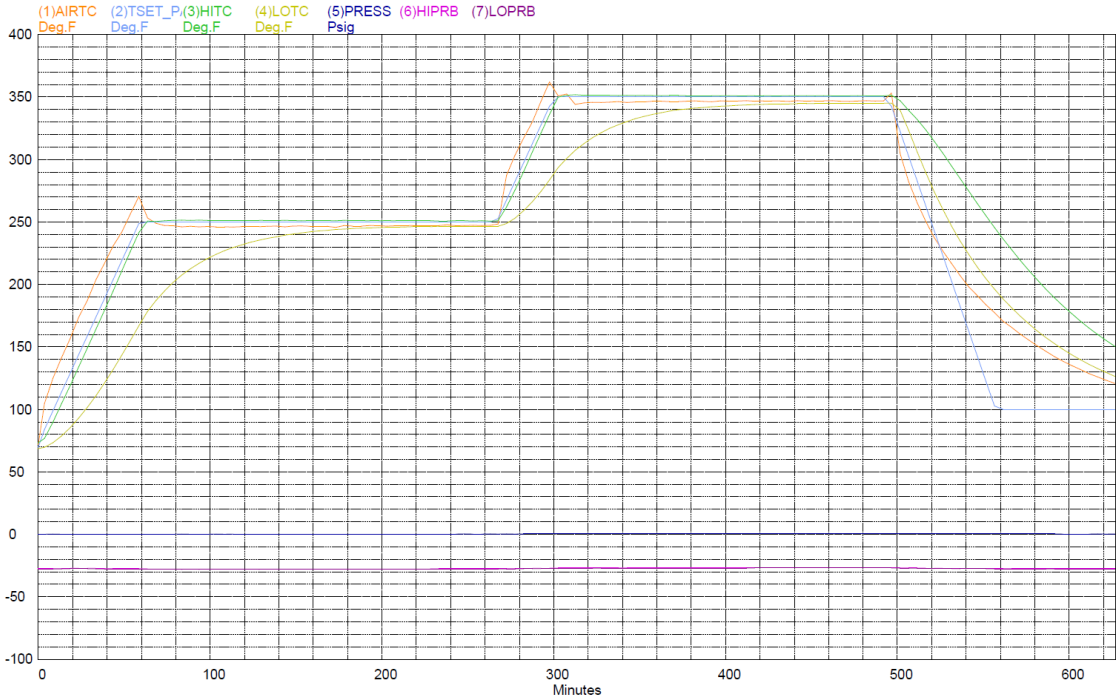
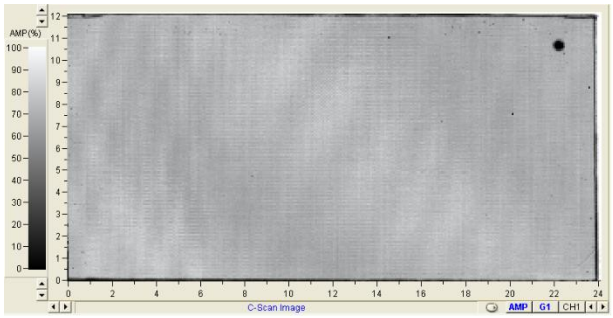
Equivalency and Qualification Panel Cure

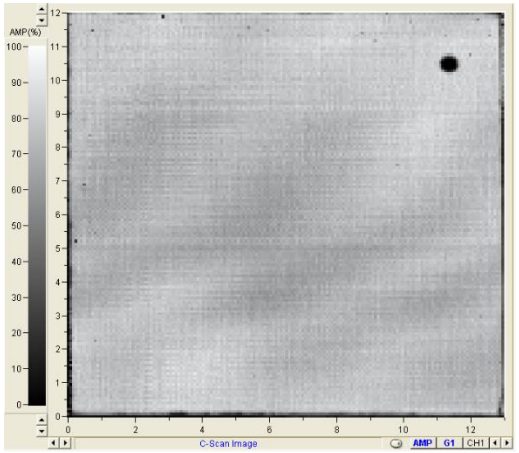
Equivalency and Qualification Parent panels cured to NPS 85321 Base Line Cure (C) with integrated post cure at 350°F

CPC Control System
NCAT
Trend Report - Primary Sensors

LoadNumber:	1560	OperatorName:	KEN VU
Equipment:	Econoclave 6x12	RecipeDesc:	FAA Repair Qual 5320 T650
Recipe Mod:	4/26/2018 2:04:58 PM	Recipe Audit #:	N/A
DataFile:	6X12_20180518-001.DAT	Report Date:	Tuesday, May 29, 2018, 4:09:39 PM
Run Start:	Friday, May 18, 2018, 7:57:12 AM	Run End:	Friday, May 18, 2018, 6:24:18 PM







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Lamina Level Test (Equivalency)

Table 3 Lamina Level Tests (Equivalency)

Layup (warp direction)	Test Type and Direction	Property	Number of Batches x Number of Panels x Number of Test Specimens Test Temperature/Moisture Condition		
			CTD	RTD (4)	ETW2
$[0]_{15}$	ASTM D3039 Warp Tension	Strength, Modulus, and Poisson's Ratio	1x2x4	1x2x4	1x2x4
$[0]_{15}$	ASTM D6641 Warp Compression	Strength and Modulus	1x2x4	1x2x4 (1)	1x2x4 (3)
$[90]_{15}$	ASTM D3039 Fill Tension	Strength and Modulus	1x2x4	1x2x4	1x2x4
$[90]_{15}$	ASTM D6641 Fill Compression	Strength and Modulus	1x2x4	1x2x4 (1)	1x2x4 (3)
$[45/-45]_{3S}$	ASTM D3518 In-Plane Shear (2)	Strength and Modulus	1x2x4	1x2x4	1x2x4
$[0]_{32}$	ASTM D2344 Short Beam	Strength	1x2x4	1x2x4	1x2x4

Laminate Level Test (Equivalency)

Table 4 Laminate Level Tests (Equivalency)

(%0°/%±45°/%90°) Actual Test Type	Test Type and Layup (3)	Property	Number of Batches x Number of Panels x Number of Test Specimens		
			Test Temperature/Moisture Condition		
			CTD	RTD	ETW2
(25/50/25 - QI) OHT1	ASTM D5766 Open Hole Tension (1) [45/0/-45/90]2S	Strength		1x2x4	1x2x4
(25/50/25 - QI) OHC1	ASTM D6484 Open Hole Compression (1) [45/0/-45/90/45/0/-45/90/-45/90]S	Strength		1x2x4 (2)	1x2x4
(25/50/25 - QI) UNC1	ASTM D6484 Unnotched Compression (1) [45/0/-45/90/45/0/-45/90/-45/90]S	Strength		1x2x4 (2)	1x2x4
(25/50/25 - QI) CAI1	ASTM D7136 & D7137 Compression After Impact (1500 in.lb/in) (2) [45/0/-45/90]3S	Strength		1x2x4	

(1) Open-hole configuration: 0.25" hole diameter, 1.5 inch width.
(2) Back-to-back strain gages needed on the first two specimens of each environment. If no buckling is observed, the remaining modulus specimens will require strain gage on one side of the specimens only. Appropriate extensometer may be used in place of the strain gage.
(3) Loading direction is generally along the 0-degree direction

Equivalency Draft Statistics

- Draft report presented to Repair Steering Committee in January
- Currently have a 92.59% pass rate
- Awaiting Fill Tension and Fill Compression to complete equivalency testing (Late June).

Equivalency Test Results for FAA Laminate Repair Study compared with Solvay (Formerly Cytec) 5320-1 T650 3k-PW fabric with 36% RC

Test	Normalized Data	Property	Environmental Condition		
			CTD	RTD	ETW2
Warp Compression	Yes	Strength	Pass	Pass	Pass
		Modulus	Pass	Pass	Pass
Warp Tension	Yes	Strength	Pass	Pass	Pass
		Modulus	Pass	Pass	Pass with Mod CV
In-Plane Shear	No	0.2% Offset Strength	Pass	Pass	Failed by 2.23%
		Strength at 5% Strain	Pass with Mod CV Insufficient Data	Pass	Pass
		Modulus	Pass	Pass	Failed by 1.08%
Short Beam Strength	No	Strength	Pass	Pass	Pass
Open Hole Compression 1	Yes	Strength		Pass	Pass
Open Hole Tension 1	Yes	Strength		Pass	Pass
Compression After Impact 1	Yes	Strength		Pass Insufficient Data	
Cured Ply Thickness	NA	NA	Pass		
Dynamic Mechanical Analysis	Onset Storage Modulus - Dry		Pass with ±18°F RESULTS		
	Peak of Tangent Delta - Dry		Pass with ±18°F RESULTS		
	Onset Storage Modulus - Wet		Pass with ±18°F RESULTS		
	Peak of Tangent Delta - Wet		Pass with ±18°F RESULTS		

Description	Modulus	Strength
Mild Failure	% fail $\leq$ 4%	% fail $\leq$ 5%
Mild to Moderate Failure	4% < % fail $\leq$ 8%	5% < % fail $\leq$ 10%
Moderate Failure	8% < % fail $\leq$ 12%	10%< % fail $\leq$ 15%
Moderate to Severe Failure	12% < % fail $\leq$ 16%	15% < % fail $\leq$ 20%
Severe Failure	16% < % fail $\leq$ 20%	20% < % fail $\leq$ 25%
Extreme Failure	20% < % fail	25% < % fail

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Laminate Level Repair Tests 50:1 Scarf Ratio

Table 5 Laminate Level Repair Tests 50:1 Scarf Ratio

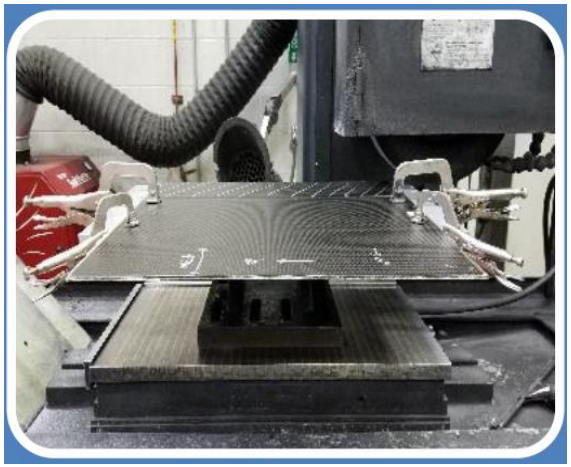
(%0°/%±45°/%90°) Actual Test Type	Test Type and Layup (2)(3)	Property	Number of Batches x Number of Panels x Number of Test Specimens		
			Test Temperature/Moisture Condition		
			CTD	RTD	ETW2
(25/50/25 - QI) TR	ASTM D8131 Tension Repair [45/0/-45/90/45/0/-45/90/-45/90]S	Strength & Modulus	3x2x3	3x2x3	3x2x3
(25/50/25 – QI) UNCR	ASTM D6484 Un-Notched Compression Repair [45/0/-45/90/45/0/-45/90/-45/90]S	Strength	3x2x3	3x2x3 (1)	3x2x3
(25/50/25 - QI) CAIR	ASTM D7136 & D7137 Compression After Impact (1500 in.lb/in) (2) [45/0/-45/90/45/0/-45/90/-45/90]S	Strength	3x2x3	3x2x3 (1)	3x2x3

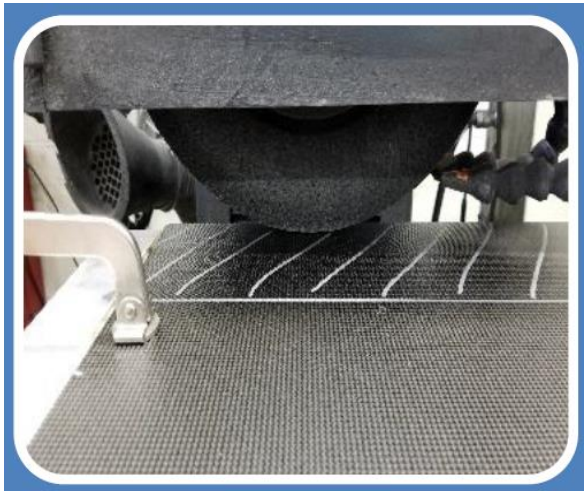
Laminate Level Repair Tests 30:1 Scarf Ratio

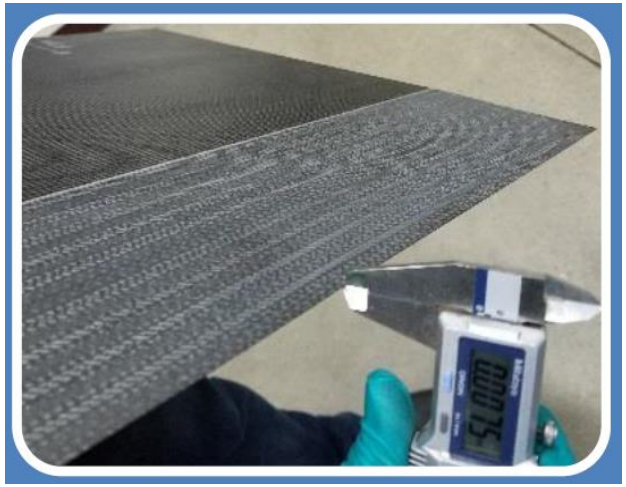
Table 6 Laminate Level Repair Tests 30:1 Scarf Ratio

(%0°/%±45°/%90°) Actual Test Type	Test Type and Layup (2)(3)	Property	Number of Batches x Number of Panels x Number of Test Specimens		
			Test Temperature/Moisture Condition		
			CTD	RTD	ETW2
(25/50/25 - QI) TR	ASTM D8131 Tension Repair [45/0/-45/90/45/0/-45/90/-45/90]S	Strength & Modulus	1x2x4	1x2x4	1x2x4
(25/50/25 – QI) UNCR	ASTM D6484 Un-Notched Compression Repair [45/0/-45/90/45/0/-45/90/-45/90]S	Strength	1x2x4	1x2x4 (1)	1x2x4

Parent Panel Scarfing







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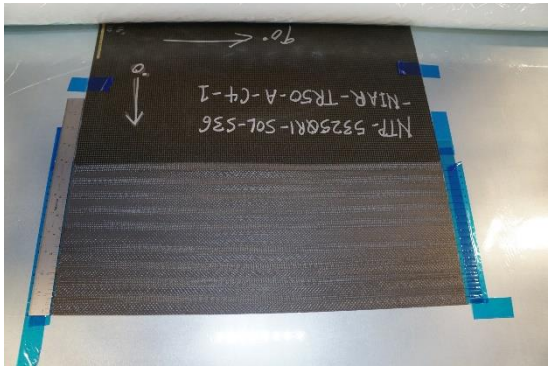
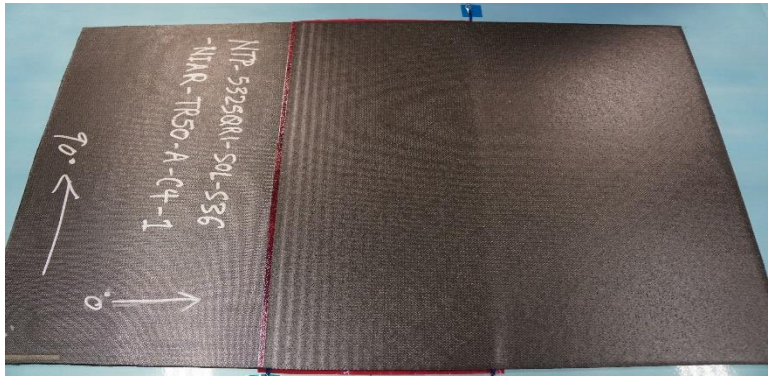
Parent Laminate Repair – NTP-5352QR1-SOL-S36-NIAR-TR50-A-C4-1



Parent laminate panel scarfed, taped to tool and repair alignment lines have been marked with the appropriate ply number.

Once alignment marks are applied, the scarf surface is cleaned and the film adhesive is applied. 5th ply is laid up.

All repair plies have been laid up. The 20th ply has about a 0.40” overhang from the parent panel scarf. The adhesive has a 0.75” overhang from the edge of the scarf.

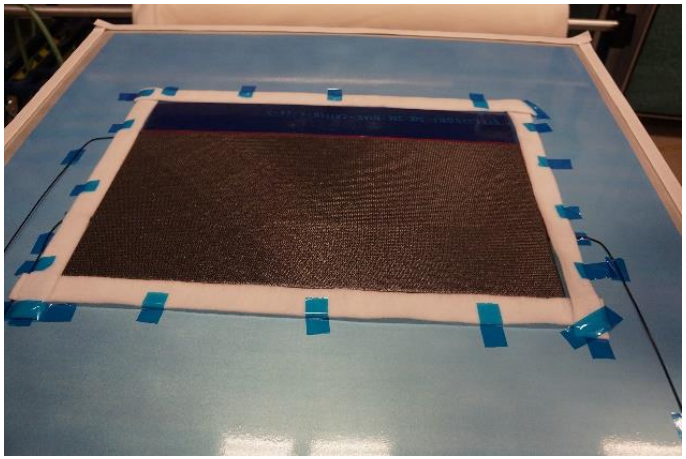


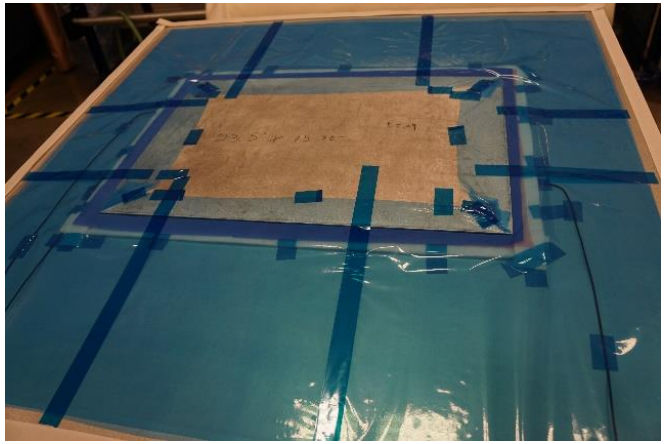
Outcome of the layup / debulk process.

Bagging Preparation

- Heat blankets were selected to correspond to about 8”-16” greater in each dimension of the final panel. This allows the heat blanket to heat the tool underneath the panel.
- The tool size should be only 8” greater in each dimension than the heat blanket, which allows room for sealant tape and vacuum ports
  - The reduced tool size makes the heating process easier for the hot bonder
- The caul plate for the panels were sized to the final panel dimensions and were all 0.09” thick, according to the process specifications.

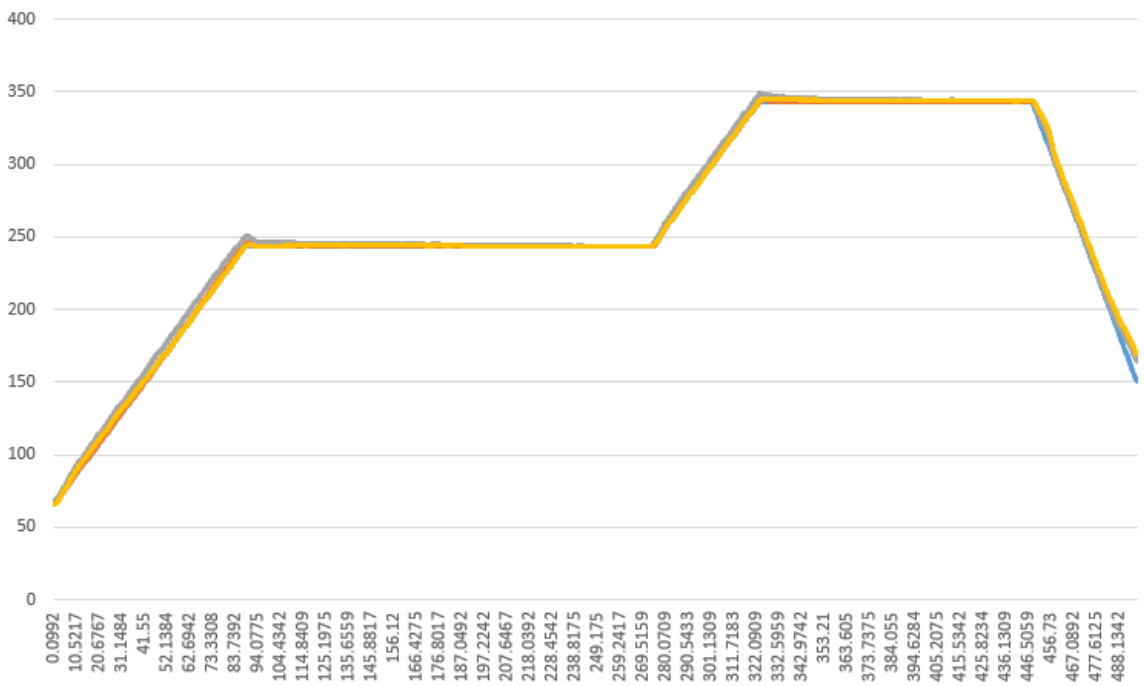
Parent Laminate Cure – NTP-5352QR1-SOL-S36-NIAR-CAI150-C-C2-3

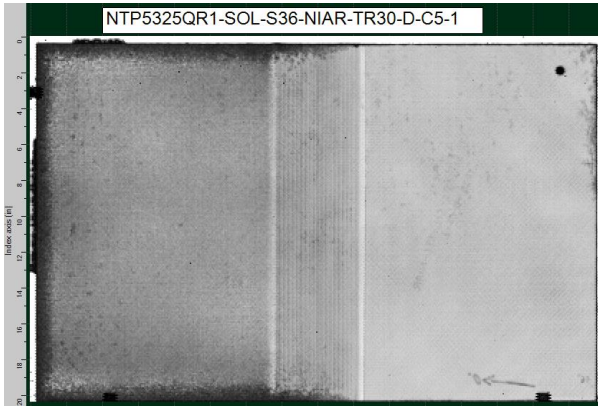


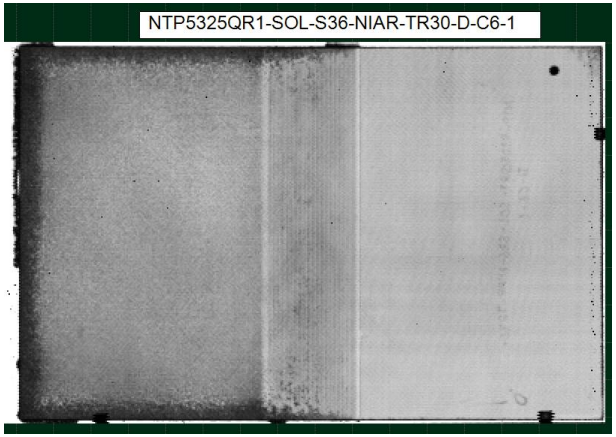


Repair Panel Cure – Hot Bonder

Bagging and cure conducted to NPS 80530R. Repair Cure cycle with a two stage cure. 250°F for 180-210 minutes and a ramp up to 350°F for 120-150 minutes.







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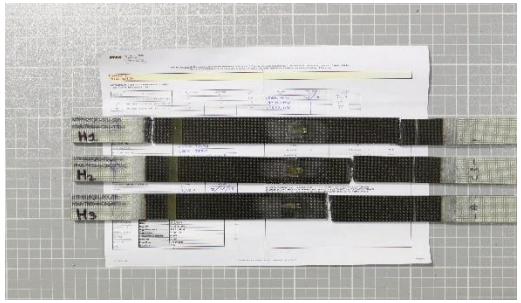
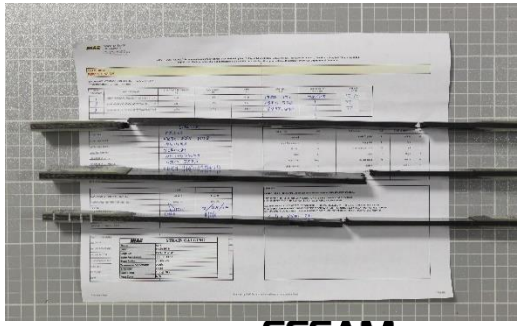
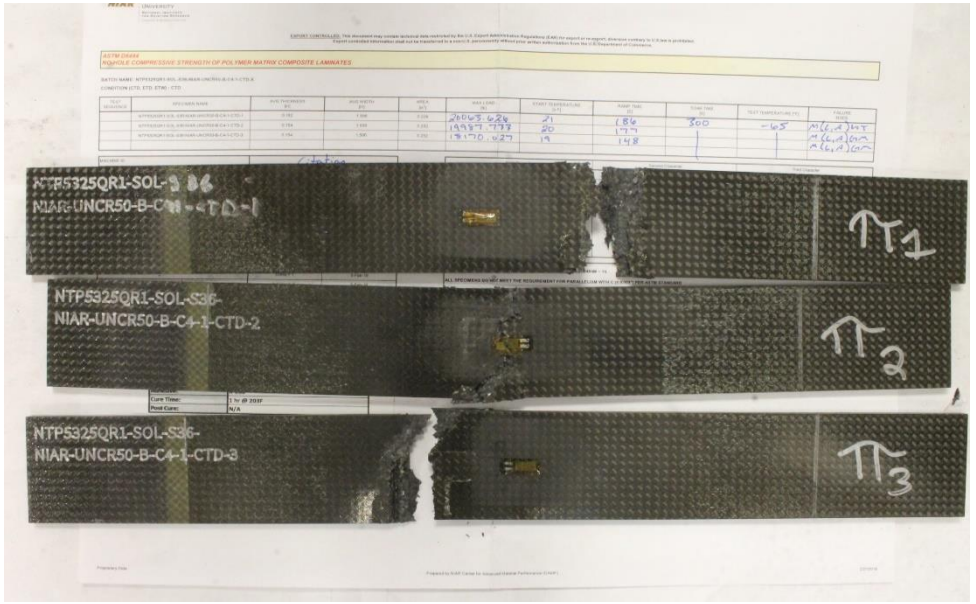
Repair Testing Status

- All non-ETW tension and compression testing is complete. The ETW samples have been conditioning for 65 days and need about 2-3 more weeks to reach the saturation requirements (160°F & 85% RH).
- CAI Repair CTD is complete with RTD testing underway. The ETW samples have been conditioning for 65 days and need about 2-3 more weeks to reach the saturation requirements.
- Fluid Sensitively Samples have undergone specimen conformity and the majority will be tested in the month of June.







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Repair Testing Status

- The available test data is pretty consistent within the test category.
- When comparing the repaired data to the baseline data there is a significant knockdown for the tension data.
- Less significant for the compression testing.

			Test Conditions		
Test Type	Table	Method	CTD	RTD	ETW2
Warp Tension	3	ASTM D3039	108.021 ksi	121.316 ksi	135.562 ksi
Repaired Tension (scarf ratio 50:1)	5	ASTM D8131 - Repair Section	67.380 ksi	78.602 ksi	*
Repaired Tension (scarf ratio 30:1)	6	ASTM D8131 - Repair Section	67.042 ksi	79.263 ksi	*
UNC	4	ASTM D6484 (no hole)	n/a	89.200 ksi	*
Repaired Compression (scarf ratio 50:1)	5	ASTM D6484 (no hole)	85.141 ksi	80.468 ksi	*
Repaired Compression (scarf ratio 30:1)	6	ASTM D6484	87.620 ksi	79.708 ksi	*
CAI	4	ASTM D7137	n/a	32.873 ksi	n/a
Repaired CAI	5	ASTM D7137	33.013 ksi	28.606 ksi**	*

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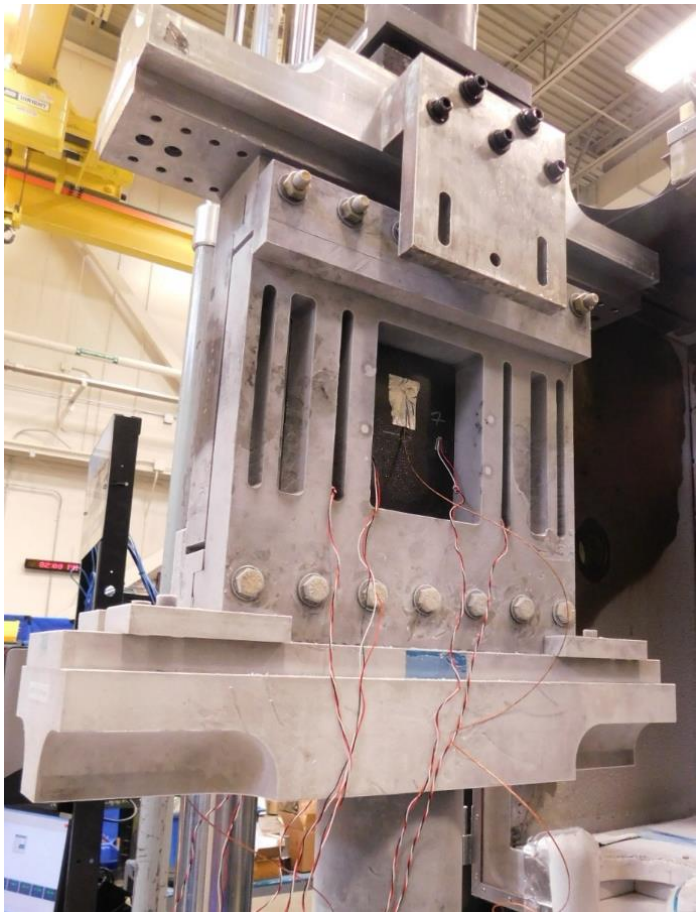
Test Setup Pictures



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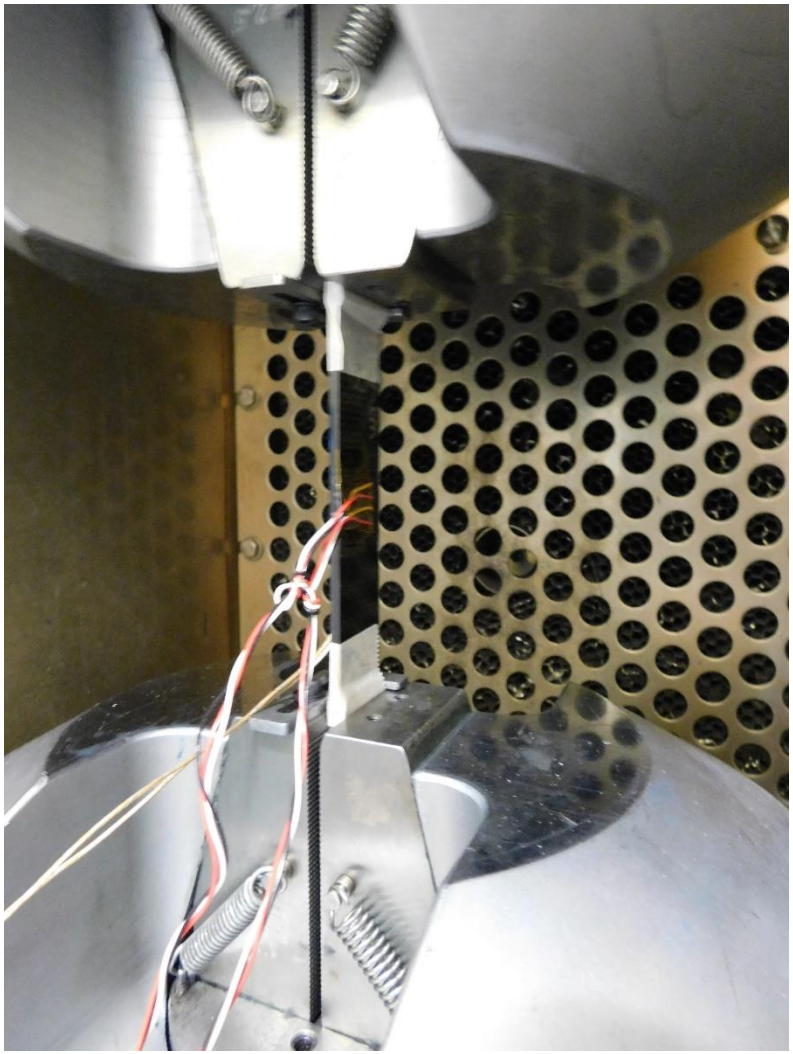
Test Setup Pictures



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Repair Qualification Timeline

	Activity	Completion Date	Milestone / Deliverable	Completed
1.1	Survey - Develop survey questions and administer to PMC repair community - Collect survey results and analyze for input on material selection	12/15/2016	Deliverable	✓
1.2	Industry Steering Committee - Establish group of participants - Create online portal for document sharing and data repository	1/31/2017	Milestone	✓
1.3	Preliminary drafts of qualification framework - Process specification - Test plan	6/30/2017	Deliverable	✓

Repair Qualification Timeline

	Activity	Target Date	Milestone / Deliverable	Completed
1.1	Qualification Material - Prepreg delivered to NIAR (no audit required as material has previously been qualified) - Adhesive delivered to NIAR – Audit complete 2/2018	1/31/2018	Milestone	✓
1.2	Trial / Screening Studies (ongoing) - Perform flex testing studies to determine optimal configuration for qualification testing. - Present data to FAA, Industry Steering Committee, NCAMP Partners	2/28/2018	Milestone	✓
1.3	Panel Fabrication at NIAR	3/1/2018	Milestone	✓
1.4	Equivalency Testing - Perform physical and mechanical testing on equivalency panels fabricated with new process specification.	6/30/2018 – CTD & RTD 6/14/2019 - ETW	Milestone	✓
1.4	Qualification Testing - Perform physical and repair specific mechanical testing on qualification panels. – Generate repair test data for qualification program.	6/30/2019	Milestone	Ongoing
1.4	Develop Statistical Guidelines based on qualification data	7/31/2019	Milestone	Ongoing
1.5	NCAMP Reports on Qualification Data - Material technical report - Statistical analysis technical report	8/15/2019	Deliverable	
1.6	CMH-17 - Submit content, data, and protocols to Composite Materials Handbook 17 (CMH-17)	10/31/2019	Deliverable	
1.7	Final Report - Final Technical Report on the Guidelines for Polymer Matrix Composite Repair Materials	10/31/2019	Deliverable	

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Additional Tasks

- **Wettability Assessment:** A critical measure of the quality of surface treatment techniques is the resulting surface contact angle, which controls the surface wettability by the adhesive. *A methodology for wettability assessment will be documented using contact angle measurement for scarfed surface inspection.*

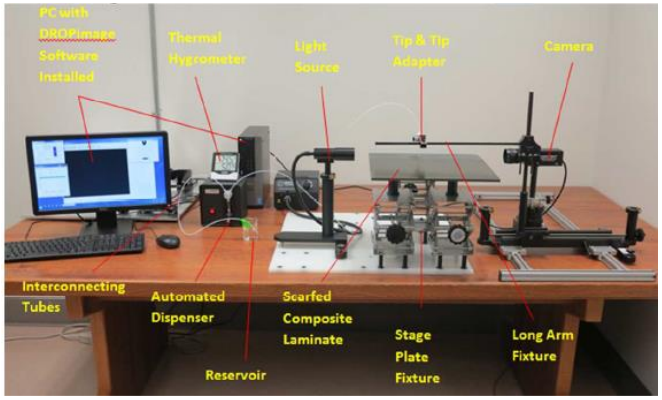

Figure 1. Example of Contact Angle Measurement Set-Up (Rame-hart Model 500)

- **Atmospheric Pressure Plasma Surface Preparation**: Surface treatment using atmospheric plasma can be used for bond quality control and assurance and incorporated into a structural repair manual to prepare a composite surface prior to bonding the repair. *A methodology for scarfed surface preparation using atmospheric pressure plasma will be developed*.

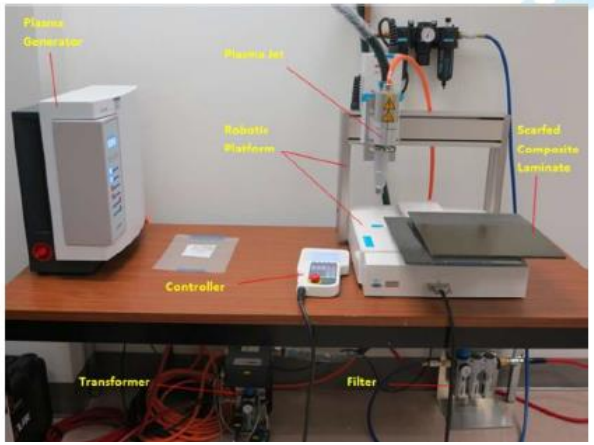

Figure 2. Example of Plasma Treatment Equipment Set-Up (PlasmaTreat FG5001)

Looking forward

- Benefit to Aviation
  - Understanding of repair processing limitations
  - Repeatability
  - Compare to non-repair processing of same material
  - Framework for qualification of repair tests
  - Impact of scarf ratio on mechanical properties
- Future needs
  - Establish a public research profile that documents specific inspection and surface preparation approaches for repair
  - Ability to perform repair in field and yield repeatable results
  - Standardized test methods for repair
  - Additional qualification and equivalency repair databases

Questions?

Don’t forget to fill out the feedback form in your packet or online at www.surveymonkey.com/r/jamsfeedback

Thank you.

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