CACRC Depot Bonded Repair Investigation – Round Robin Testing

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The Joint Advanced Materials and Structures Center of Excellence

FAA Sponsored Project Information

- Principal Investigators & Researchers
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  - Lamia Salah, Wichita State University
  - Mike Borgman, Spirit Aerosystems
- FAA Technical Monitor
  - Curtis Davies, Lin Pham
- Other FAA Personnel Involved
  - Larry Ilcewicz, Peter Shyprykevich
- Industry Participation
  - Mike Borgman, Spirit Aerosystems

Motivation – Key Issues

Adhesively Bonded Structural Repairs – Advantages

- Can restore structure's ultimate strength and fatigue capability
- Lighter than mechanically fastened repairs
- More fatigue resistant than bolted repairs

Adhesively Bonded Structural Repairs – Limitations

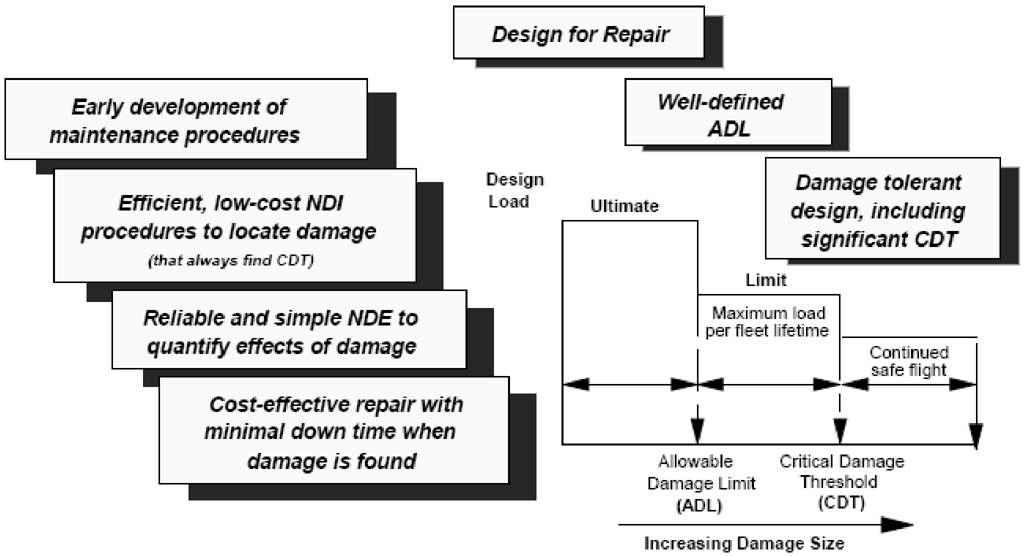
- Single Load path (no redundancy)
- No methods available to guarantee absolute bond integrity
- Adhesively bonded Repairs are **P**rocess **D**ependent

Adhesively Bonded Structural Repairs – Challenges

- Growing use of composite materials in aircraft components (flight critical, primary)
- Need to demonstrate repaired component structural integrity

Reference CMH-17 Volume 3F Section 8.3 Support Implementation A repair has the objective of restoring a damaged structure to an acceptable capability in terms of strength, durability, stiffness, functional performance, safety, cosmetic appearance or service life. Ideally, the repair will return the structure to original capability and appearance

Motivation – Key Issues



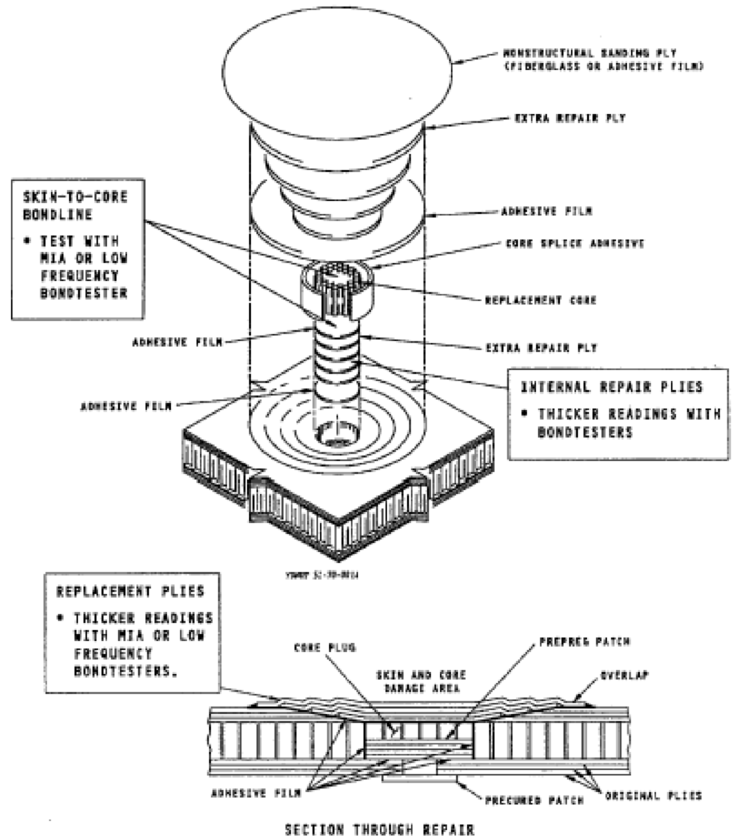
Maintenance development philosophy established during the Boeing/NASA (ATCAS) composite fuselage program

- Damage greater than ADL has to be repaired when found
- Repair philosophies have to be developed during the design phase

Reference CMH-17 Volume 3F Chapter 8 Supportability

Objective

- To investigate different variables on the performance of bonded repairs applied to sandwich structures
- To investigate the effectiveness of bonded OEM vs field repairs implemented at various OEM/ Operator depots
- To evaluate the static, fatigue and residual strength performance of OEM vs field repairs
- To evaluate the existing CACRC standards for composite repair implementation and technician training



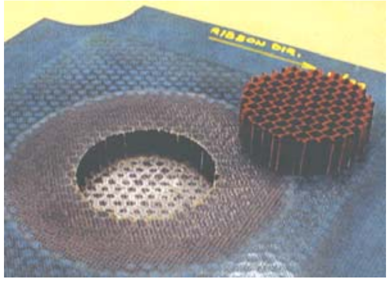
Reference SAE ARP5089

Previous Research

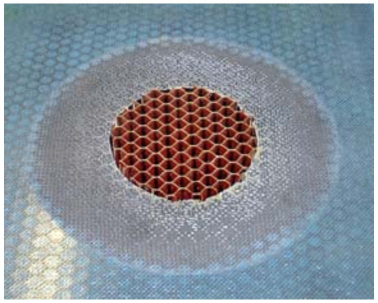
- Objective: To evaluate the strength performance of picture frame shear coupons repaired with two different methods, an OEM method and a field repair method

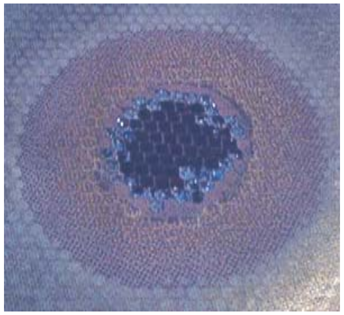
CACRC Wet lay-up Repair Method

- Repair material: Epocast 52 A/B laminating resin with TENEX Fibers
- 0.5” overlap
- 1 extra ply
- 200°F cure

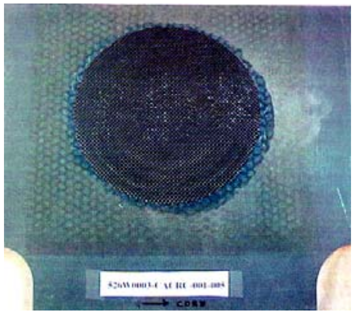


Scarfed Panel w/ Routed Core





Core Restoration

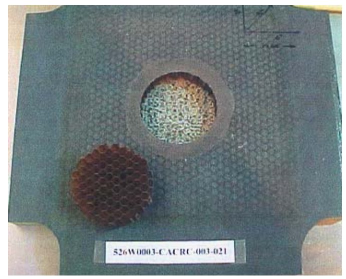


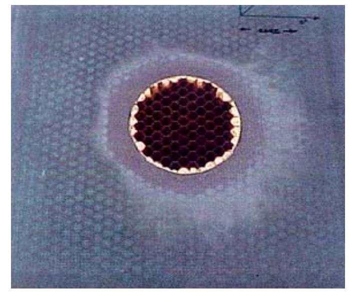
CACRC Repair

Previous Research

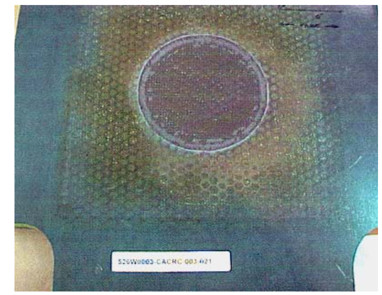
OEM Prepreg Repair Method

- Repair material:
- T300/934 3K-70-PW prepreg with FM 377S adhesive
- 0.25” overlap
- No extra ply
- 350°F cure

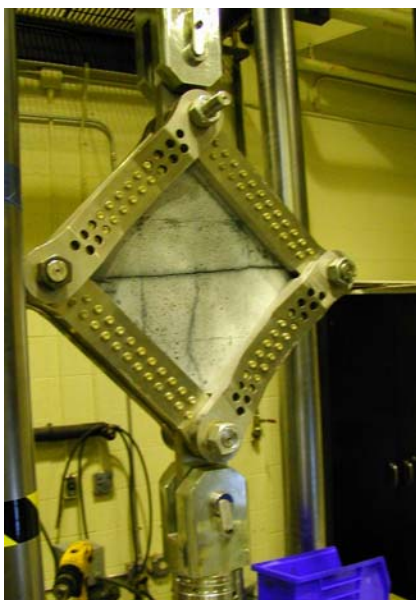




OEM core restoration



OEM prepreg repair

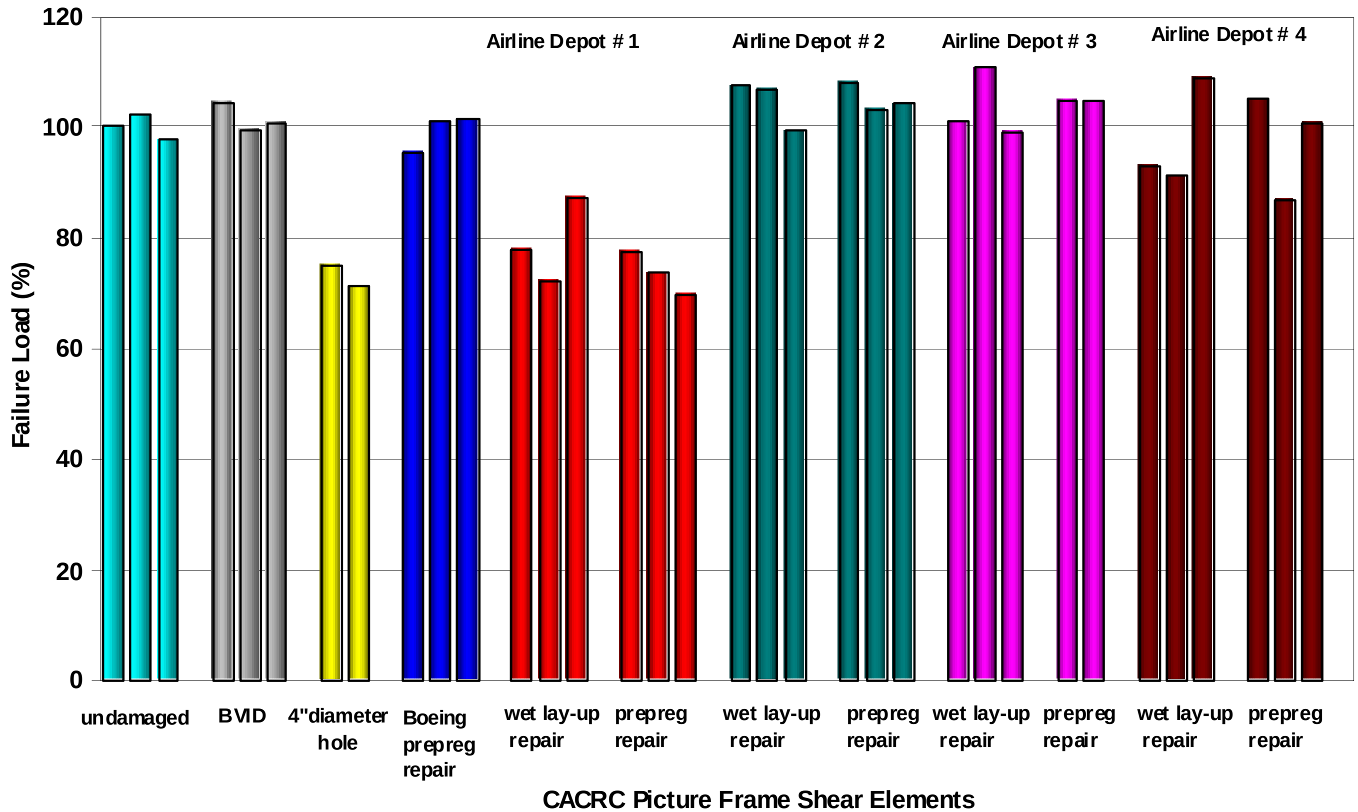


Picture Frame Shear Test Set-Up

- Picture Frame shear elements were sent to 4 different airline depots for repair
- All depots were provided shear elements to repair using the OEM and the CACRC repair procedure
- All shear elements were mechanically tested to failure

Previous Research - Results

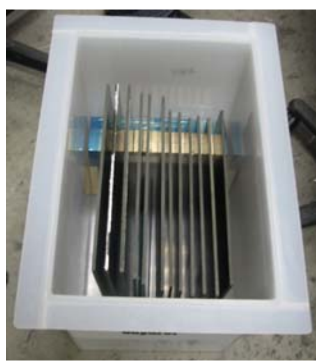
- Strength values for coupons repaired at airline depot 1 were 25% lower than the average undamaged strength. This failure is representative of an equivalent open-hole, the size of the damage site indicative of an ineffective repair



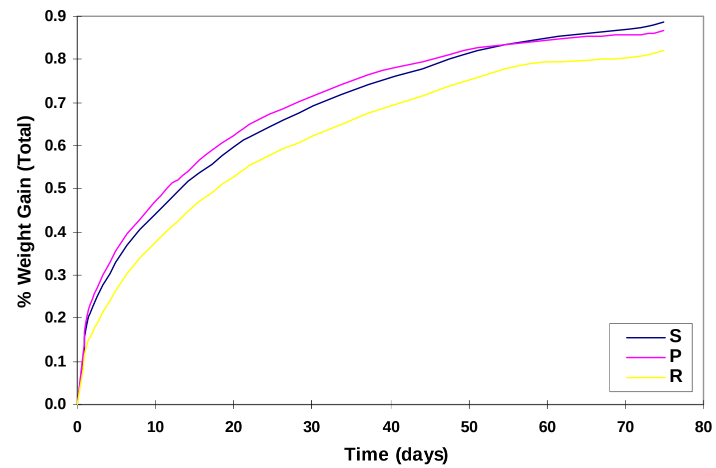
Previous Research – Contamination Investigation

- To evaluate the strength of contaminated repairs applied to laminate configurations. Five different contaminants were considered: Hydraulic oil (skydrol), jet fuel (JP8), paint stripper, water and perspiration..

Environmental Conditioning Chamber



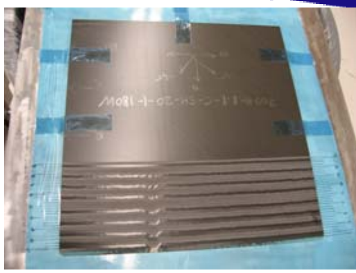
Skydrol Contamination



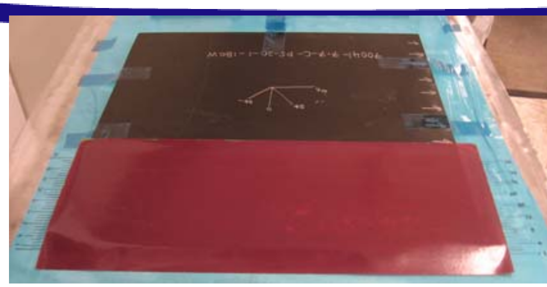
Moisture gain as a function of time

Water specimens exposed to water until equilibrium then dried back to achieve moisture contents equivalent to 0%-25%-50% and 75% saturation

Previous Research- Repair after Contaminant Exposure

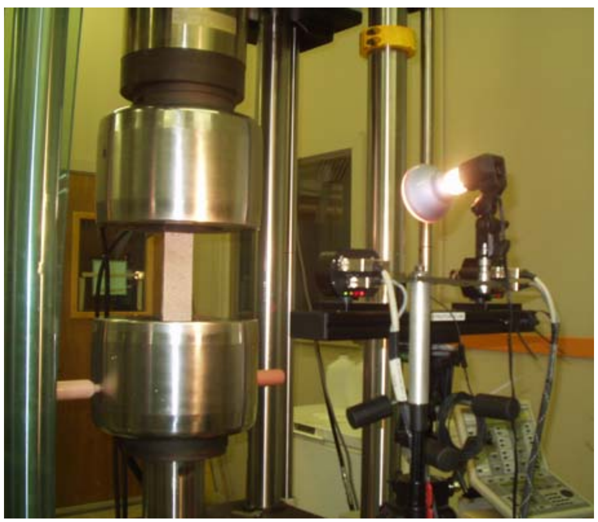


Scarfed parent panel ready for repair after contaminant exposure

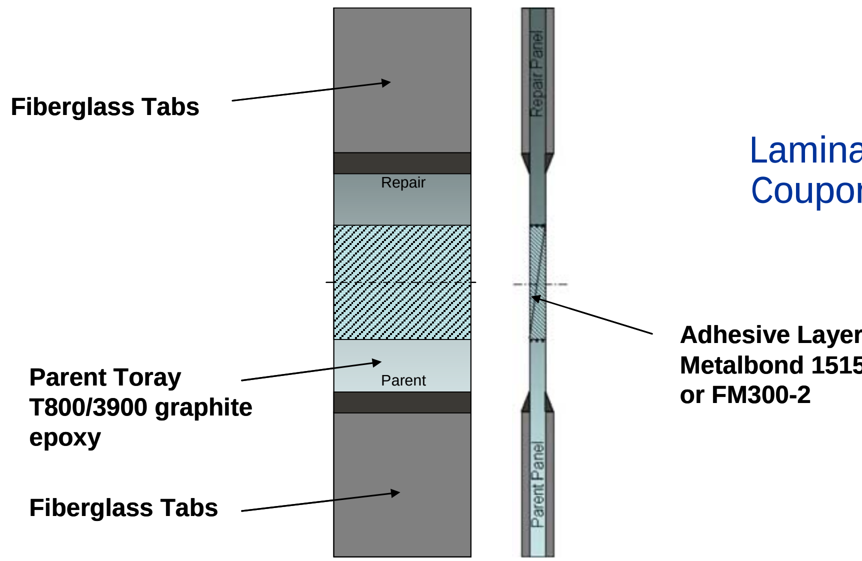


Film adhesive application

Repair ply application



Mechanical Test Set-Up



Laminate Scarf Joint Coupon Configuration

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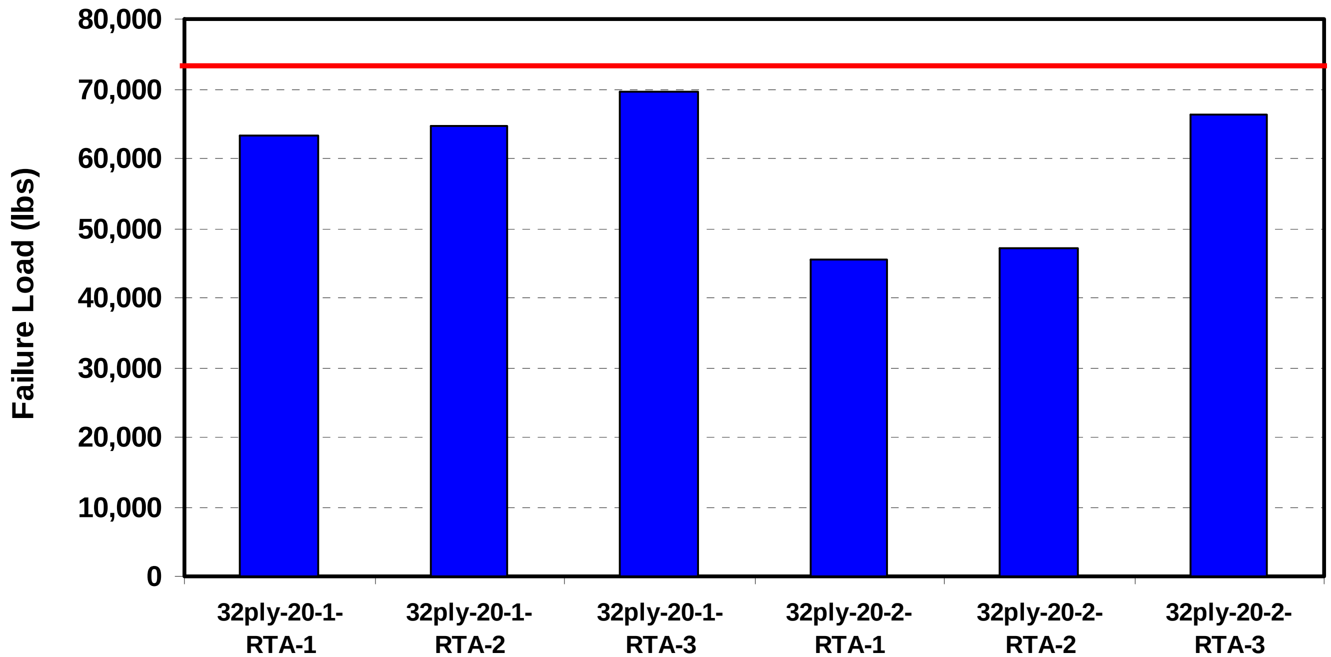
Repair after Contaminant Exposure

- Even after fully drying the repair joint, the original repair joint capability may not be restored
- WA-0 specimens are specimens that were conditioned at 145°F 85%RH until moisture equilibrium then dried back to 0% moisture



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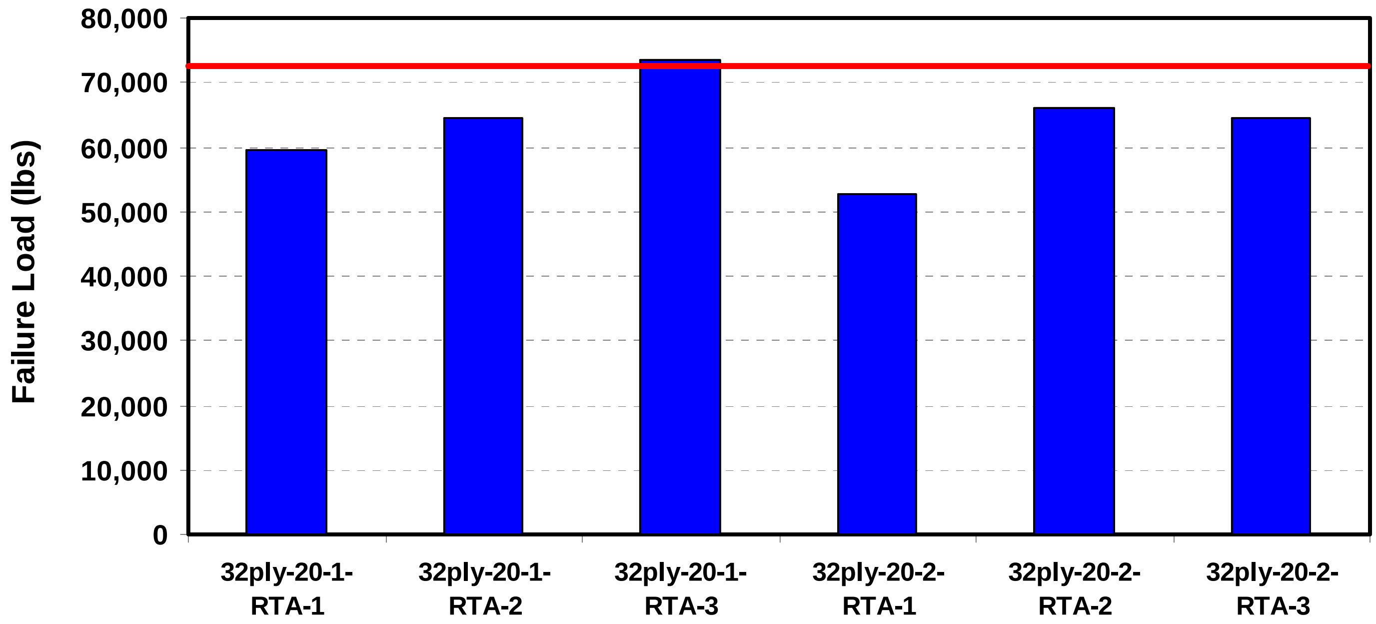
Repair after Contaminant Exposure

- WA-75 specimens are specimens that were conditioned at 145°F 85%RH until moisture equilibrium then dried back to 75% saturation

Ultimate Strength of WA-75 specimens tested at RTA



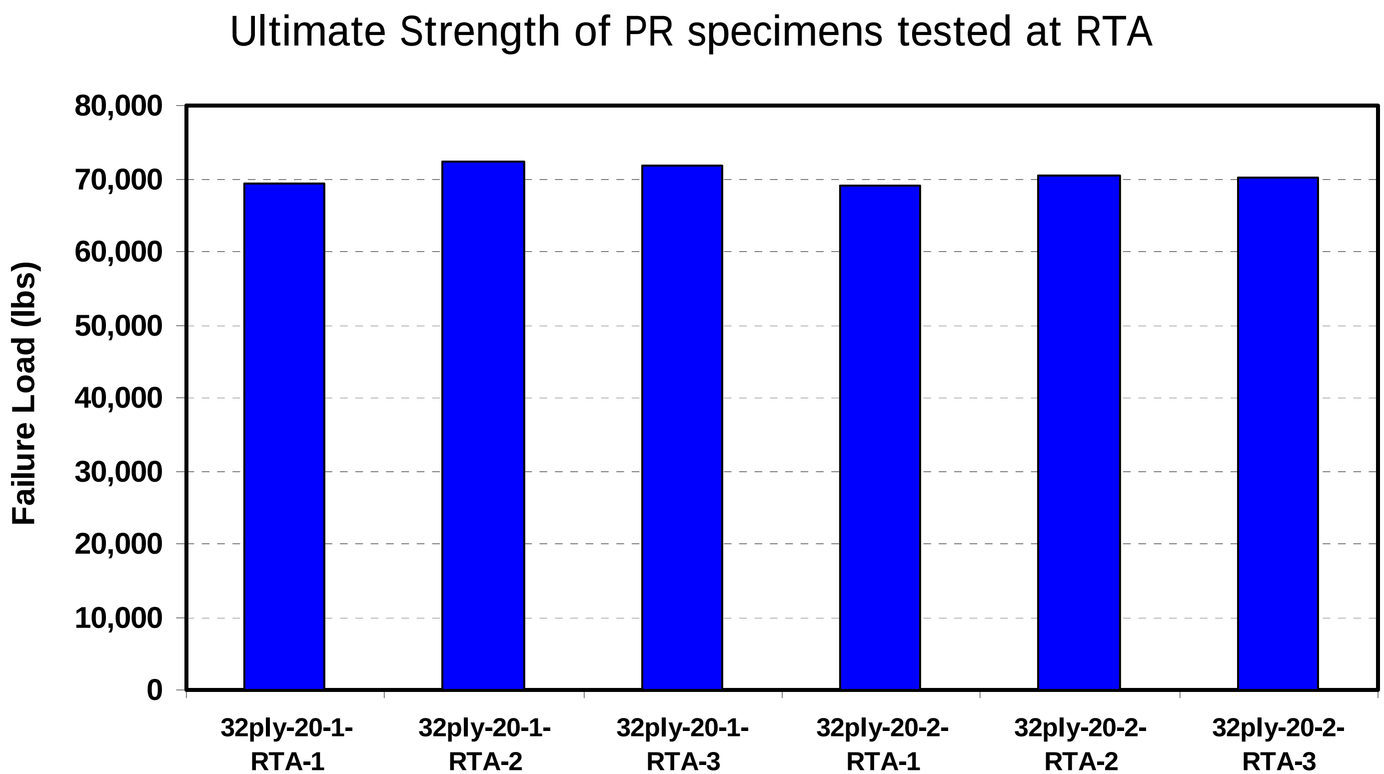
Water Absorption in Epoxy Resins

- Absorption and diffusion of water in polymeric material is related to the free volume which depends on molecular packing (degree of cure)
- Water molecules that attach to the polymer through H bonds disrupt the interchain H bonds, induce swelling and plasticize the polymer
- Moisture absorption is a function of degree of cure. Imperfectly cured systems allow moisture ingress due to the relatively loose chemical network structure
- Moisture absorption may cause irreversible changes in the epoxy network (evidence provided by the study of absorption-desorption cycling)

Ref A.F.Abdelkader, J.R.White: Water Absorption in Epoxy Resins, The effects of the Cross Linking Agent and Curing Temperature

Repair after Contaminant Exposure

- PR specimens are specimens that were subjected to perspiration (salt water) just before repair



Previous Research – Lessons Learned

Adhesively **B**onded **R**epairs are **P**rocess **D**ependent

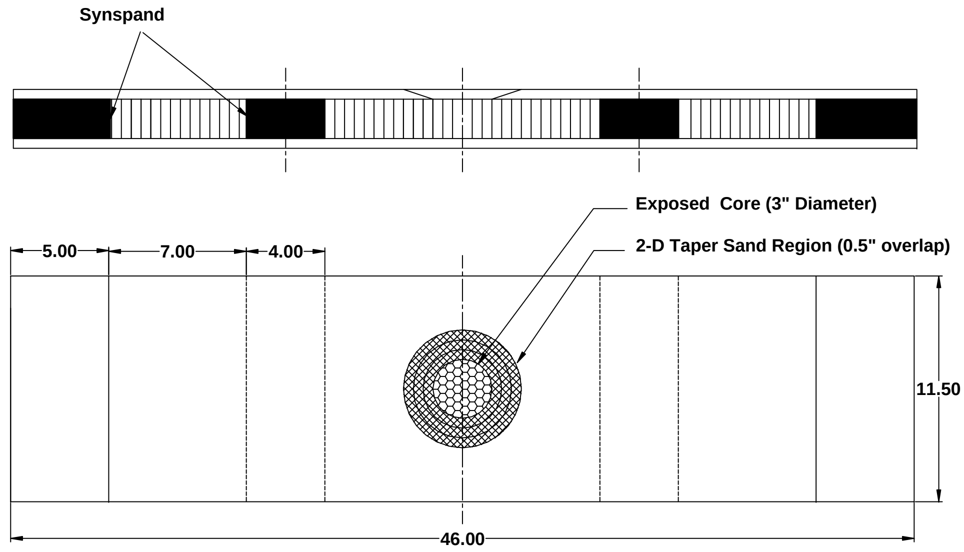
- Repair Technician Training: technician training directly affects the quality (structural integrity of a bonded repair). Only properly/ recently trained technicians should perform bonded repairs
- Cure Cycle Deviation: an improper cure cycle will yield a deficient repair
- Contaminated Repair Surface: pre-bond moisture, contaminated repair surface will yield a substandard bonded repair

Bonded **R**epair **Q**uality **A**ssurance

- Control of incoming material
- Process Control
- NDI

Proposed Research – Sandwich Coupon Configuration

- Large beams, 12” x 48” with the repair tested in compression
- 3-ply facesheets, 1/8” core cell size, 2” thick



- Parent Material: T300/ 934 with FM 377S adhesive
- Repair Materials: OEM repair using parent system (350°F cure)
  Field repair 1 using Hexcel M20 PW (250°F cure) - Prepreg
  Field repair 2 using Epocast 52A/B - Wet lay-up

Sandwich Test Matrix

- A 2.5” hole diameter will be used to simulate damage on all coupons
- Detailed test matrix is outlined in figure 1 below
- Airline depots: Northwest/ Delta, United (4 Depots)

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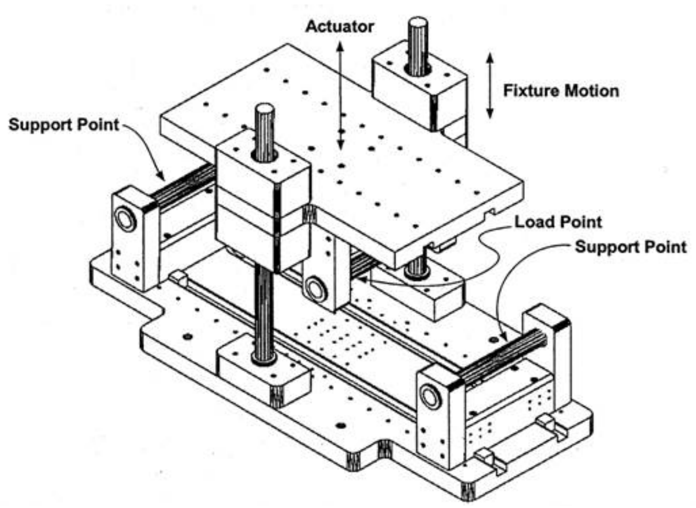
Figure 1 : CACRC Round Robin Test Matrix

Repair Station	Coupon Configuration	Repair Type	Number of test Replicates Loading Mode		
			Compression Static RTA	Compression Static ETW	Compression RS ETW
OEM	Pristine/ Undamaged	N/A	6	6	6
OEM	2.5" hole	None		3	3
OEM	2.5" hole	2D-OEM		3	3
Field Station 1	2.5" hole	2D-R1		3	3
Field Station 1	2.5" hole	2D-R2		3	3
Field Station 2	2.5" hole	2D-R1		3	3
Field Station 2	2.5" hole	2D-R2		3	3
Field Station 3	2.5" hole	2D-R1		3	3
Field Station 3	2.5" hole	2D-R2		3	3
Field Station 4	2.5" hole	2D-R1		3	3
Field Station 4	2.5" hole	2D-R2		3	3
Total			6	36	36

Mechanical Test Set-Up

- Four-point Bending Test Set-up
- MTS hardware and software used to control the test
- Repaired elements tested for ultimate strength and fatigue capability
- Elements cycled for 165000 cycles to demonstrate repair acceptability
- Residual strength performed after fatigue



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Status/ Benefits to Aviation

- NIAR will provide detailed Repair procedures to be reviewed by OEM (Airbus and Boeing)
- Approved repair procedures will be supplied along with coupons to OEM/ field stations for repair
- Repair technician level of training and cure profile, detailed processes will be documented
- Planning for panel manufacture in progress

Benefits to Aviation

- To investigate the effectiveness of OEM vs field repairs and the variability due to repair implementation at various operator depots.
- To identify key elements in the implementation of bonded repairs that ensure repeatability and structural integrity of these repairs
- To provide recommendations pertaining to repair technician training and repair process control