Effects of Several Variables on the performance of Repairs Applied to Laminate and Sandwich Structures

July 10th, 2007 The Joint Advanced Materials and Structures Center of Excellence

Research Team

- Principal Investigators & Researchers
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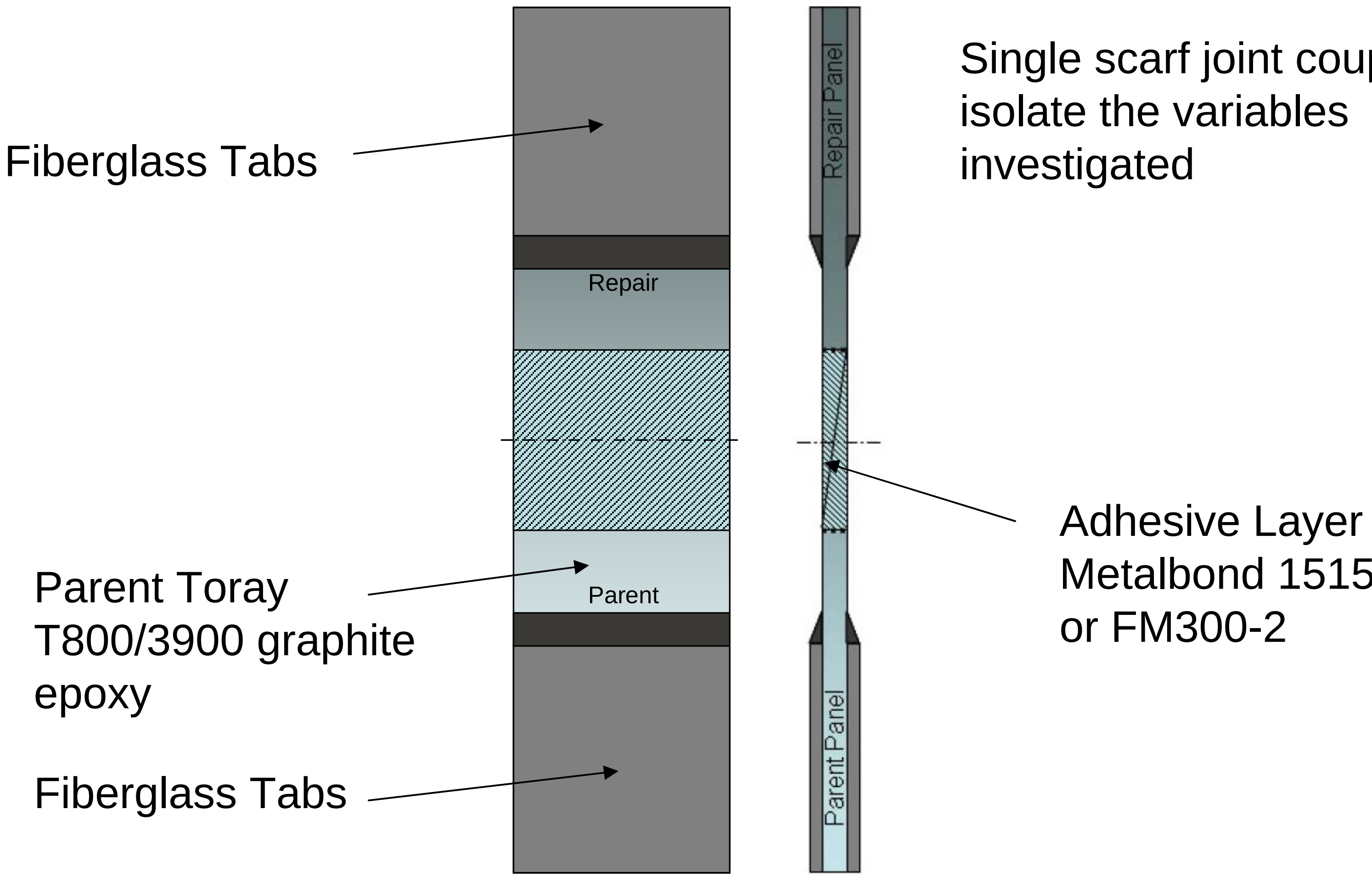
  - Dr. Charles Yang, Wichita State University
  - Dr. Bill Stevenson, Irish Alcalen (chemical analysis)
  - Mike Borgman, Hawker Beechcraft
- FAA Technical Monitor
  - Curtis Davies
- Other FAA Personnel Involved
  - Peter Sheprykevich, Larry Ilcewicz
- Industry Participation
  - Spirit Aerosystems
  - Mike Borgman & Mike Mott Hawker Beechcraft
  - Pierre Harter and Amador Motos, Adam Aircraft

Objective

To investigate different variables on the performance of repairs applied to solid laminates and sandwich structures

- **To generate baseline repair data (static and fatigue) for both laminate/ sandwich configurations using OEM/ Factory but also field repairs**
- **To evaluate the strength/ durability of poorly bonded and/or contaminated repairs that passed NDI (Laminate/Sandwich)**
- **To evaluate the existing CACRC standards for repair and provide recommendations pertaining to process improvement to ensure repair bond repeatability and structural integrity**
- **To evaluate the damage tolerance of repairs subjected to BVID inflicted at three different locations on the repair (Laminate)**

Laminate Repair Coupon Configuration



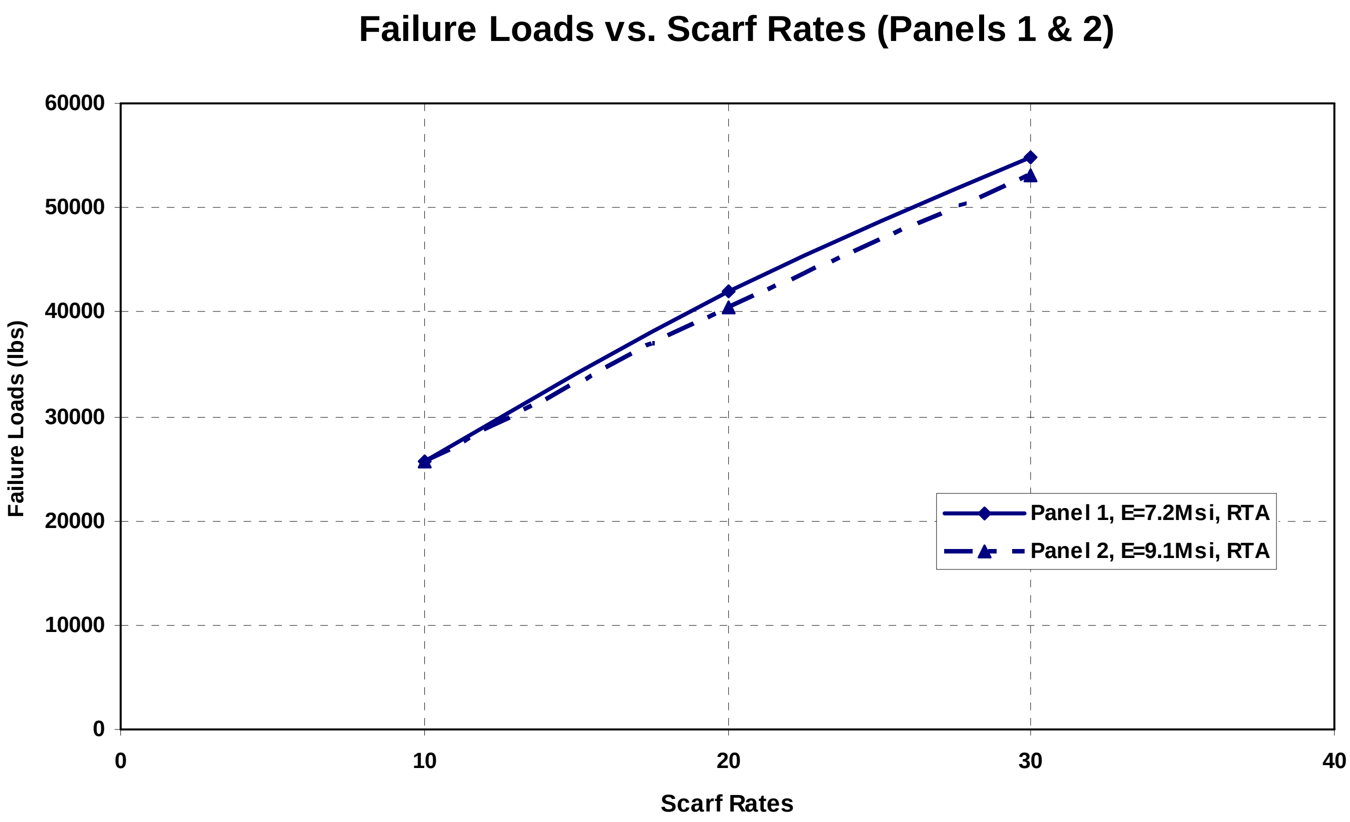
Single scarf joint coupon to isolate the variables investigated

Methodology
OEM Repair Material Evaluation

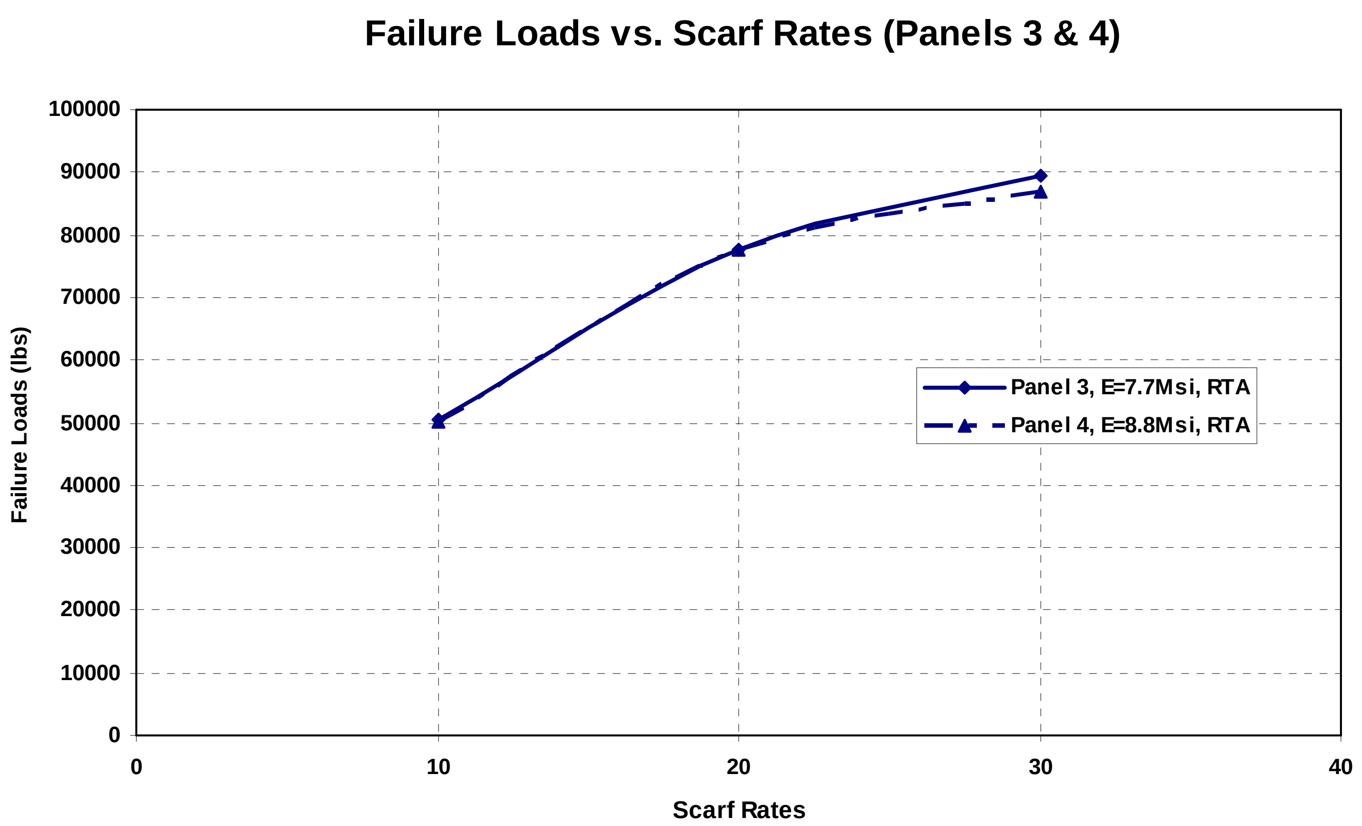
- **To generate baseline repair data with the parent material used as the repair material (OEM repair), 96 coupons used for the investigation**

				STATIC	FATIGUE
Panel #	**Thickness (in)**	**E (Msi)**	**Scarf Rate**	RTA	RTA
1	0.1332	7.2	10	6	3
			20	6	3
			30	3	3
2		9.1	10	6	3
			20	6	3
			30	3	3
3	0.2368	7.7	10	6	3
			20	6	3
			30	3	3
4		8.8	10	6	3
			20	6	3
			30	3	3

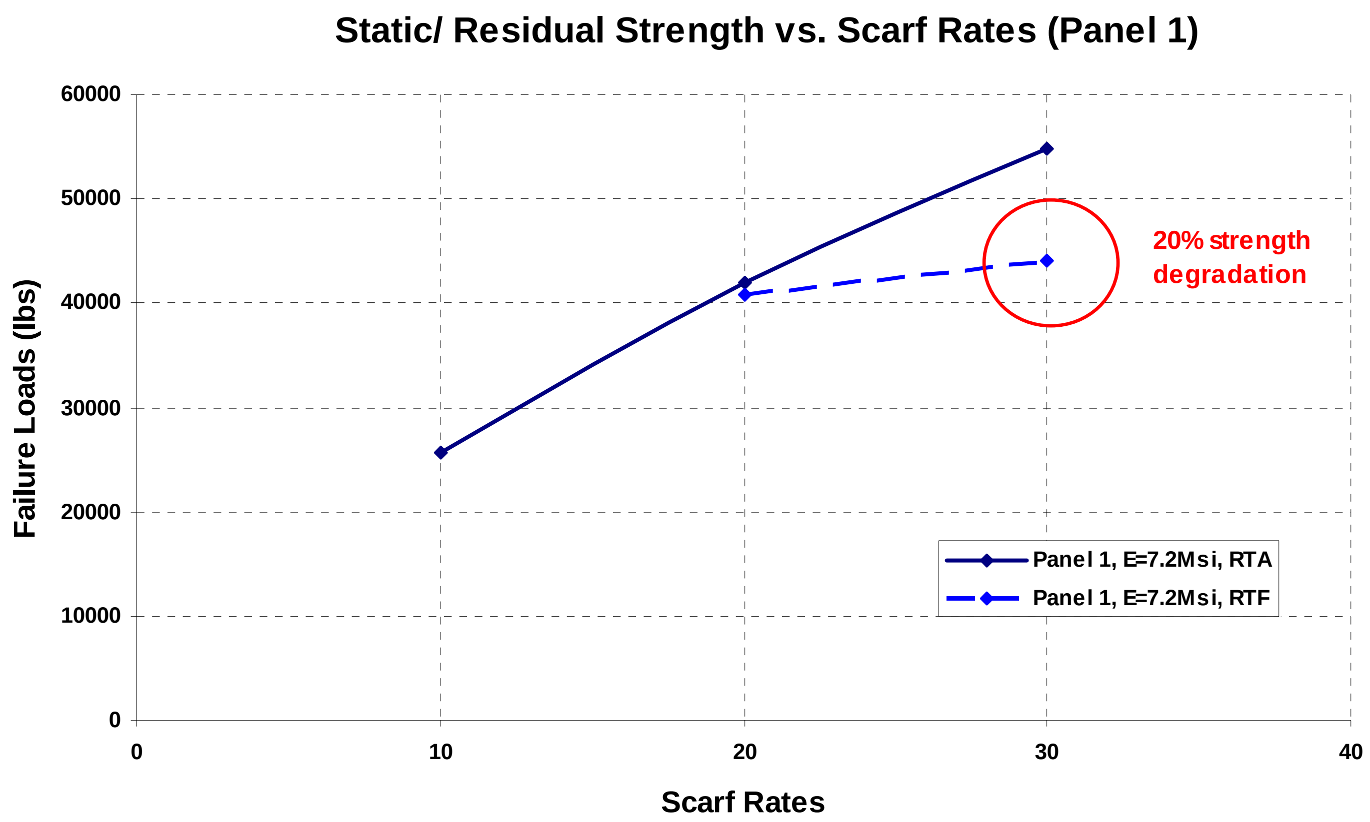
Methodology
OEM Repair Material Evaluation



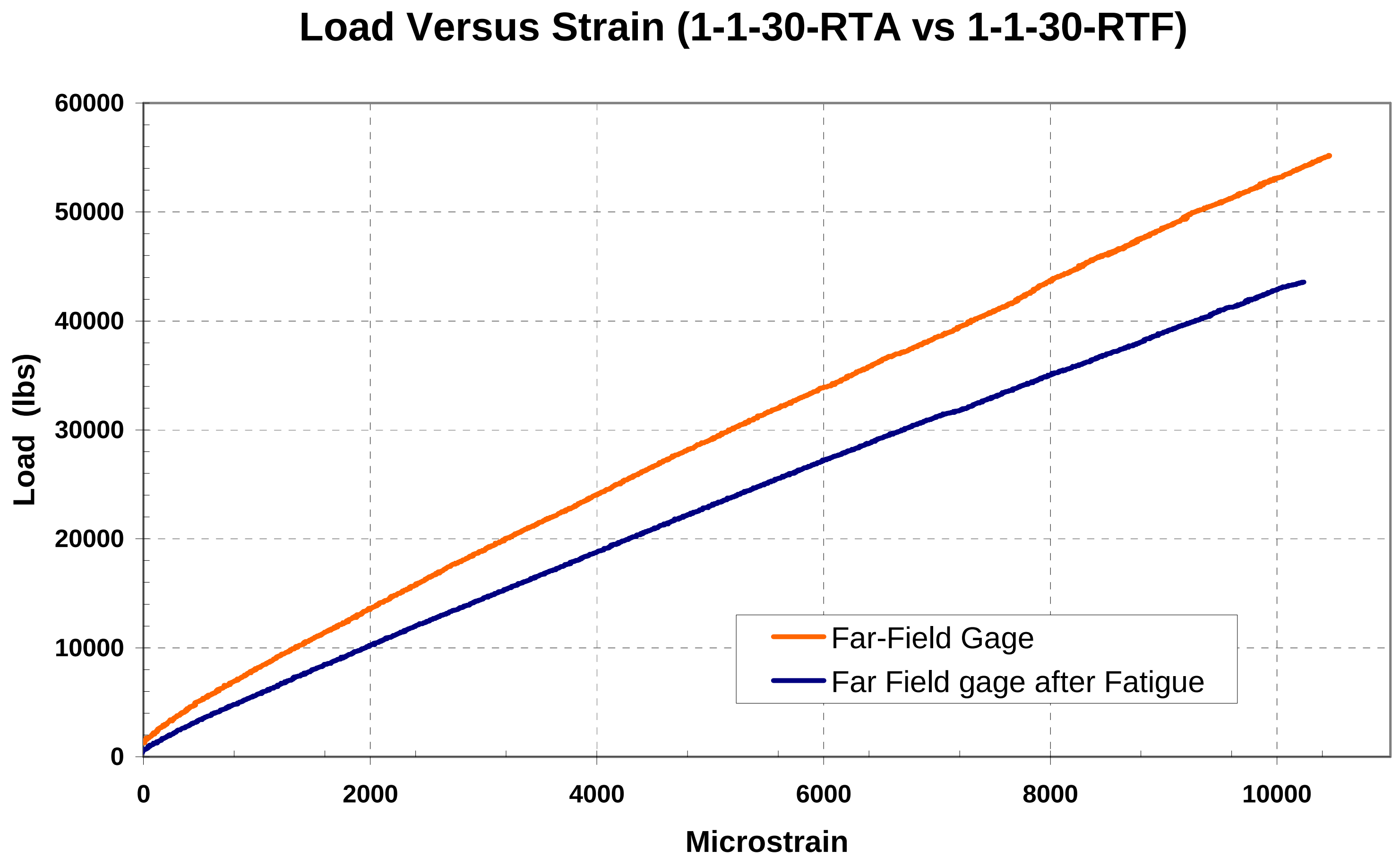
Methodology
OEM Repair Material Evaluation



Methodology
OEM Repair Material Evaluation



Methodology
OEM Repair Material Evaluation



Methodology - OEM Repair Material Evaluation- Summary

- Bonded Repair performance is dependent on repair processes
- Overall increased static performance with increased repair size
- Stiffer panels tend to have a lower strength capability than panels with lower stiffness (more pronounced poisson's effects)
- All -20 and -30 repairs survived 165000 cycles of fatigue at 3000 microstrain demonstrating acceptability of these repairs at that strain level
- The thin panels residual strength after fatigue was 20% lower than their ultimate static strength capability due to a change in compliance after fatigue (plastic deformation in the adhesive bondline)

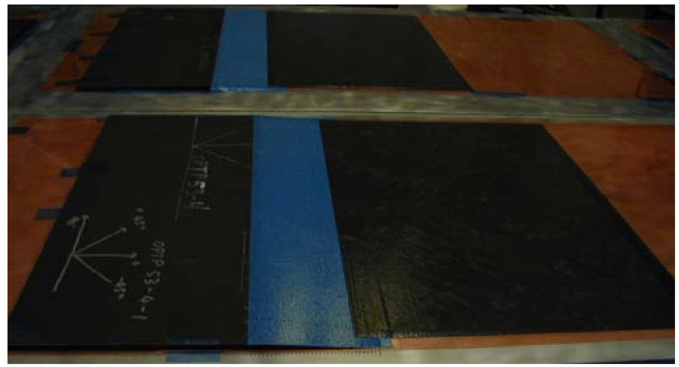
Methodology
Field Repair Material Evaluation

- To generate baseline repair data for a candidate field repair material (ACG T800/ MTM45-1), 72 coupons used for this investigation

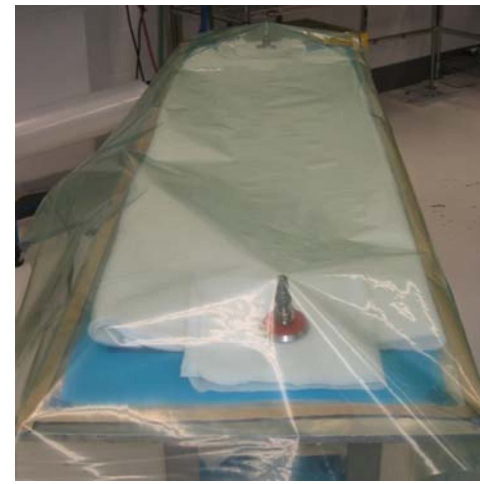
				STATIC	FATIGUE
Panel #	**T (in)**	**E (Msi)**	**Scarf Rate**	RTA	RTA
1	0.1332	7.2	10	3	3
			20	3	3
			30	3	3
2		9.1	10	3	3
			20	3	3
			30	3	3
3	0.2368	7.7	10	3	3
			20	3	3
			30	3	3
4		8.8	10	3	3
			20	3	3
			30	3	3

Methodology
Field Repair Material Evaluation

Scarf Machining

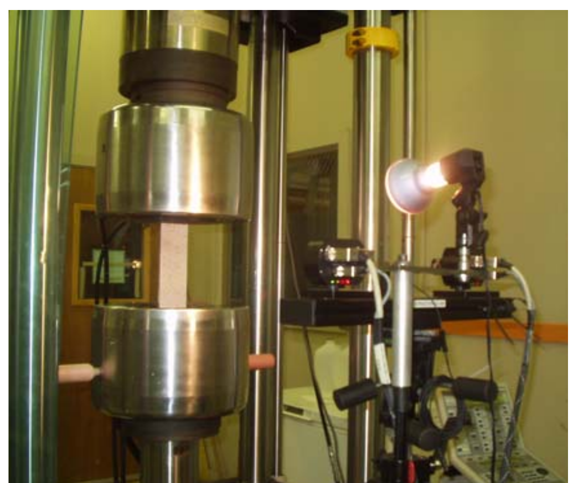


Repair Implementation



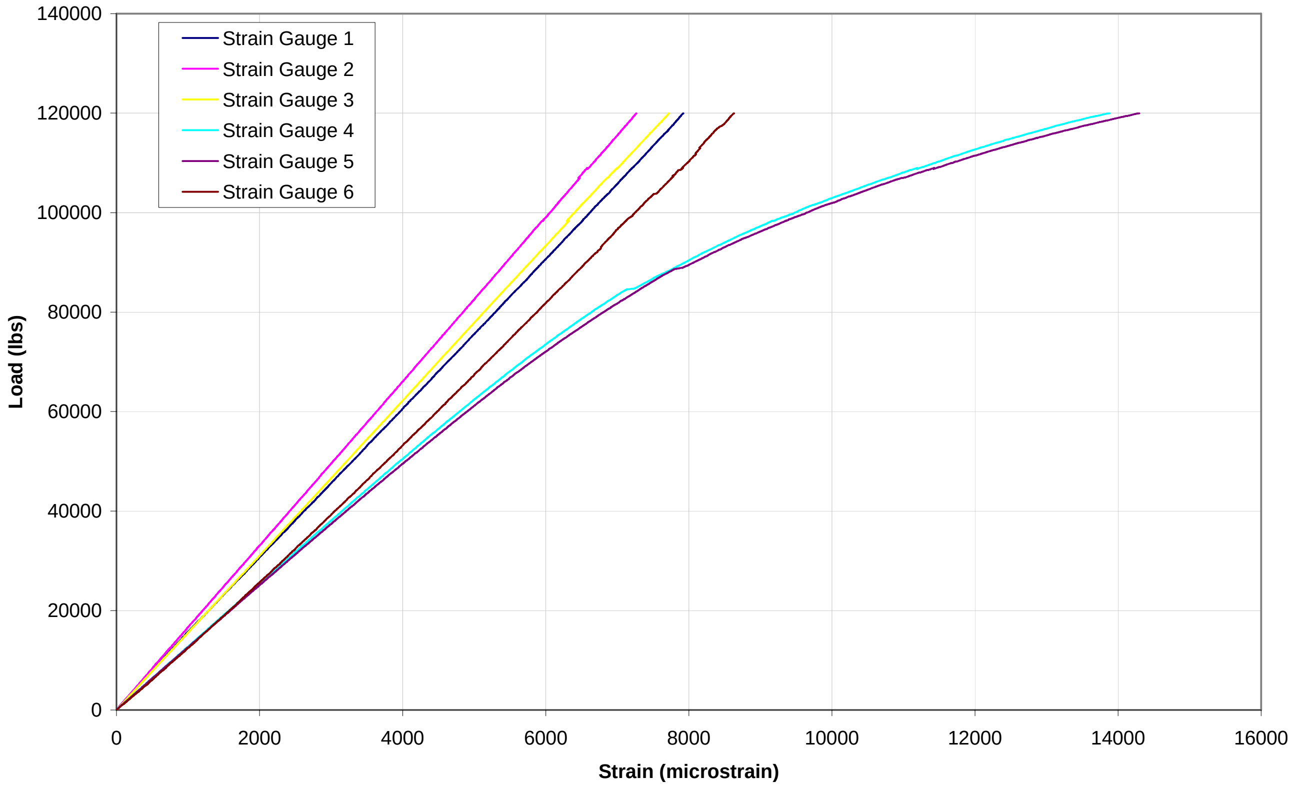
Repair Bagging

Scarfed Panels



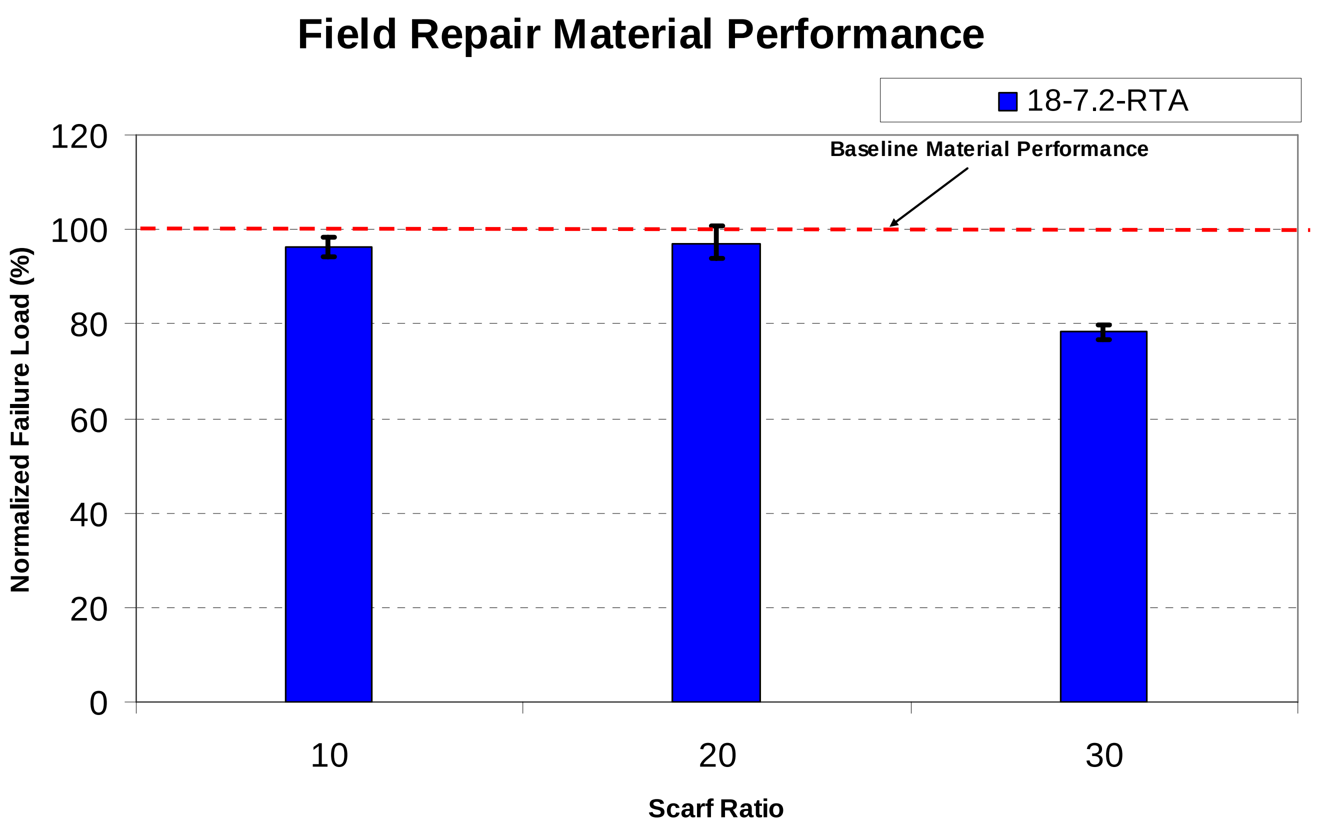
Mechanical Testing

Results
Field Repair Material Evaluation



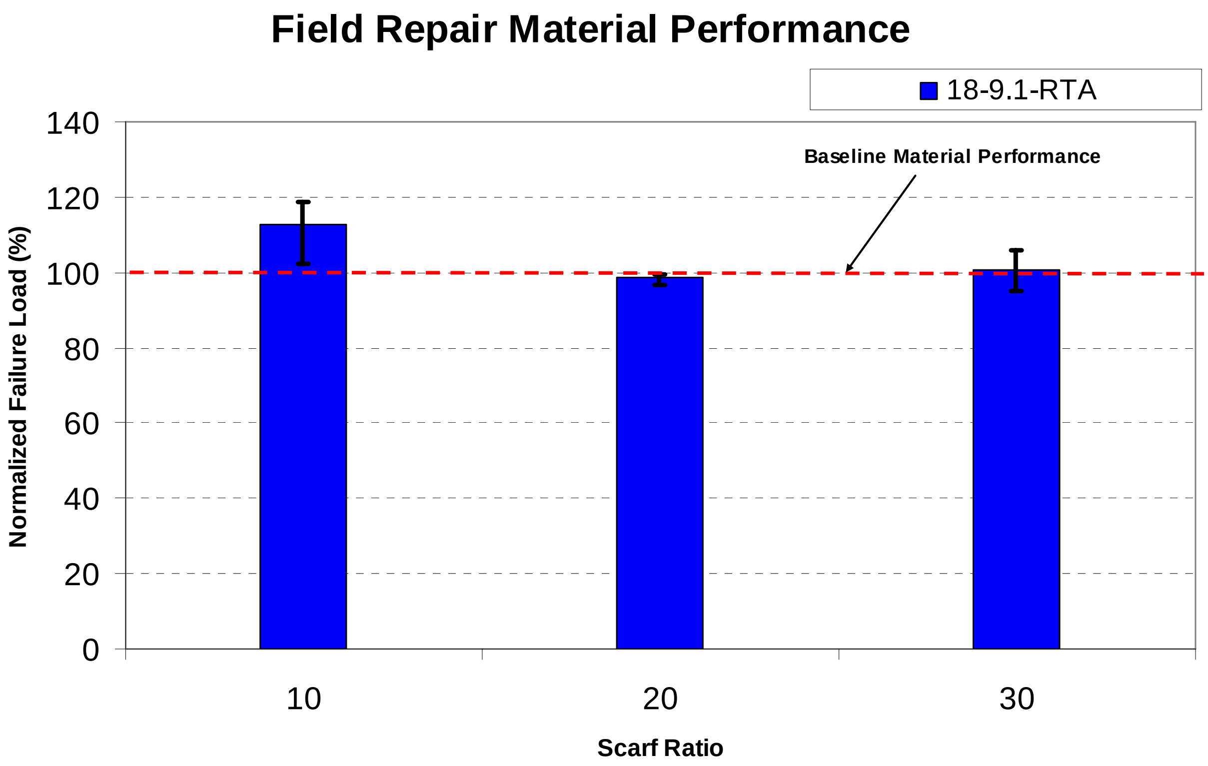
- **RTA static results showed comparable repair performance of ACG T800/MTM45-1 with respect to Toray T800/3900**

Results
Field Repair Material Evaluation

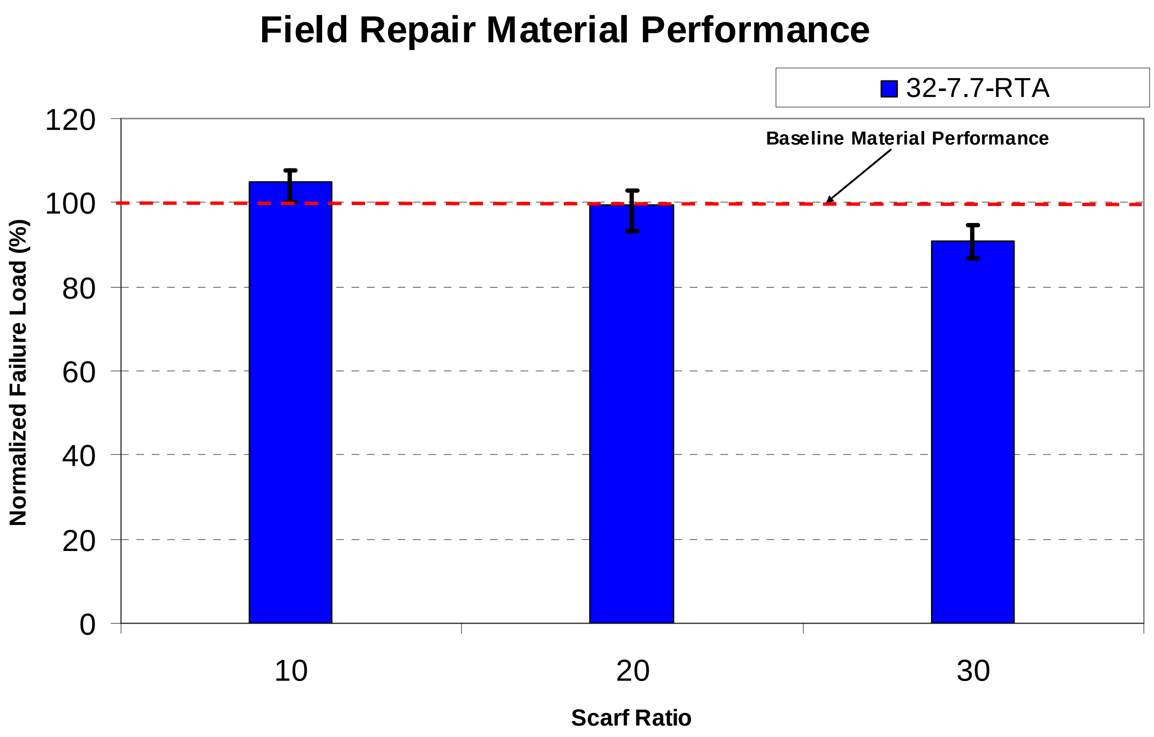


100% represents the failure load of the same coupon repaired with the parent material.

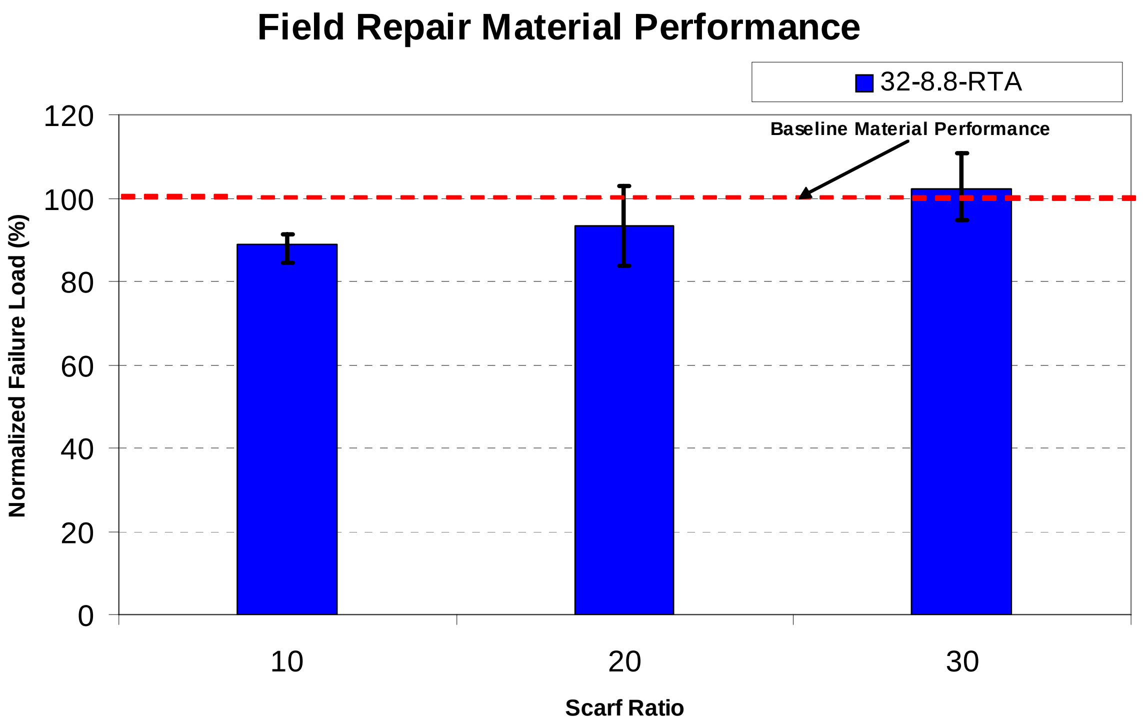
Results
Field Repair Material Evaluation



Results
Field Repair Material Evaluation



Results
Field Repair Material Evaluation

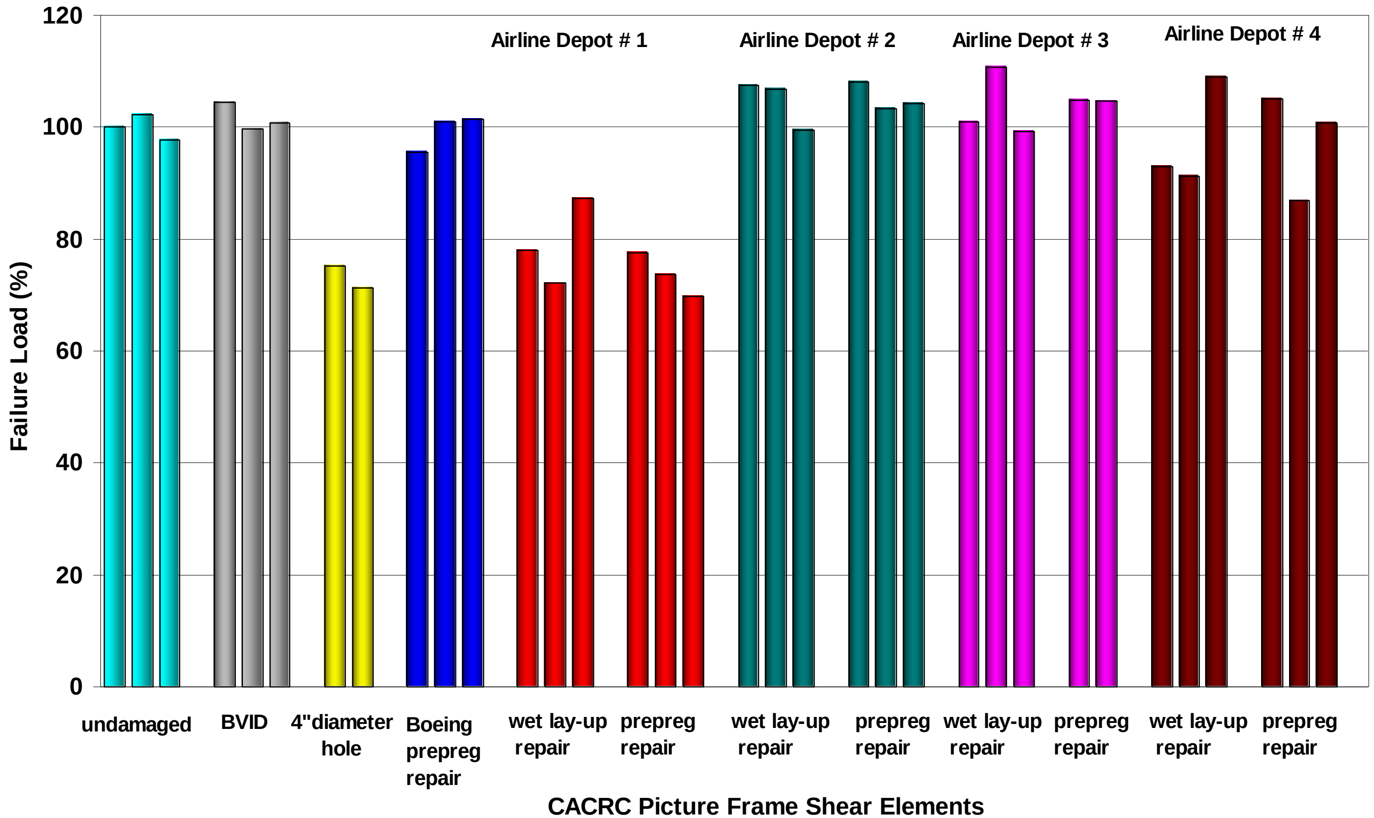


Methodology - Field Repair Material Evaluation- Summary

- **Static Strength performance of the field repair material is very comparable to that of parent material (at least 90% original strength is restored for most cases)**
- **Material is cured at 250°F under vacuum**
- **A few specimens (-20 and -30) failed in fatigue at a 3000 microstrain level but achieved at least one fatigue design lifetime**

Effects of Non-Conforming Process Parameters

- The quality of training and experience of repair technicians is directly associated with the technician's successful implementation of a repair
- Process deviation directly affects the strength of the repair



Methodology
Effects of Contamination

➢ **To evaluate the strength of contaminated repairs applied to laminate configurations. Five different contaminants are considered: Hydraulic oil (skydrol), jet fuel (JP8), paint stripper, water. The effects of each one of the contaminants is being evaluated according to the proposed test matrix. A total of 168 contaminated coupons are being used for this evaluation.**

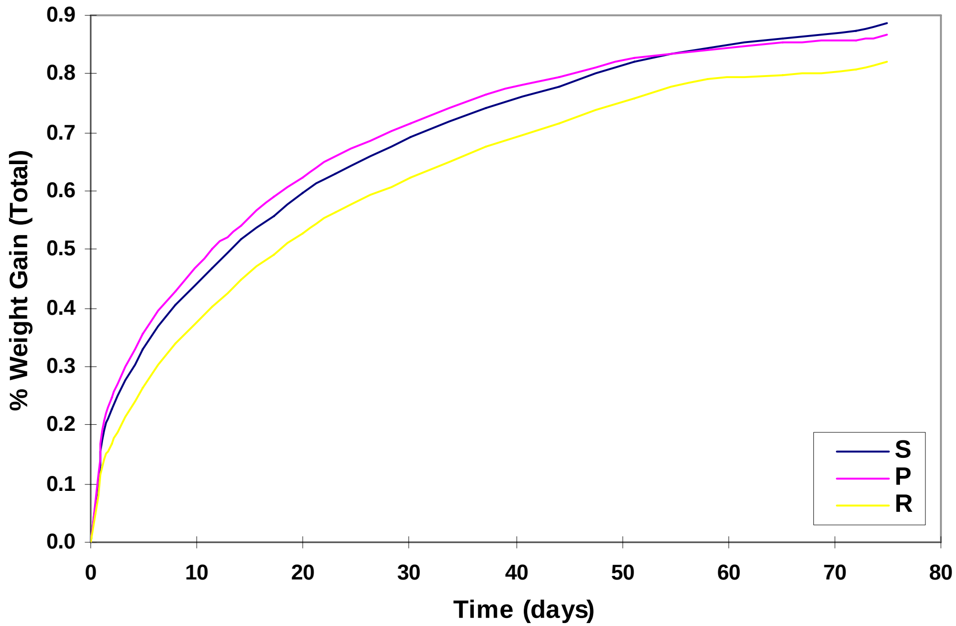
Modulus	scarf rate	Test Condition	**Contamination**													
			Skydrol		Jet Fuel		Paint Stripper		Water							
									75%		50%		25%		0%	
7.7	10	RTA	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	20	RTA	3	3	3	3	3	3	3	3	3	3	3	3	3	3
8.8	10	RTA	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	20	RTA	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Contamination Test Matrix (Laminate)

Methodology

Effects of Contamination

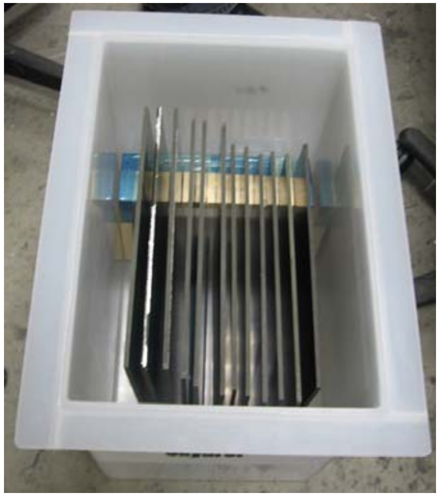
Contaminant	Minimum Soak Time
Jet Fuel, JP8	30 days
Paint Stripper	6 days
Skydrol	30 days
Water	30 days



After saturation, coupons will be dried to achieve saturation levels of 0%,25%, 50%, 75% and 100%

Methodology

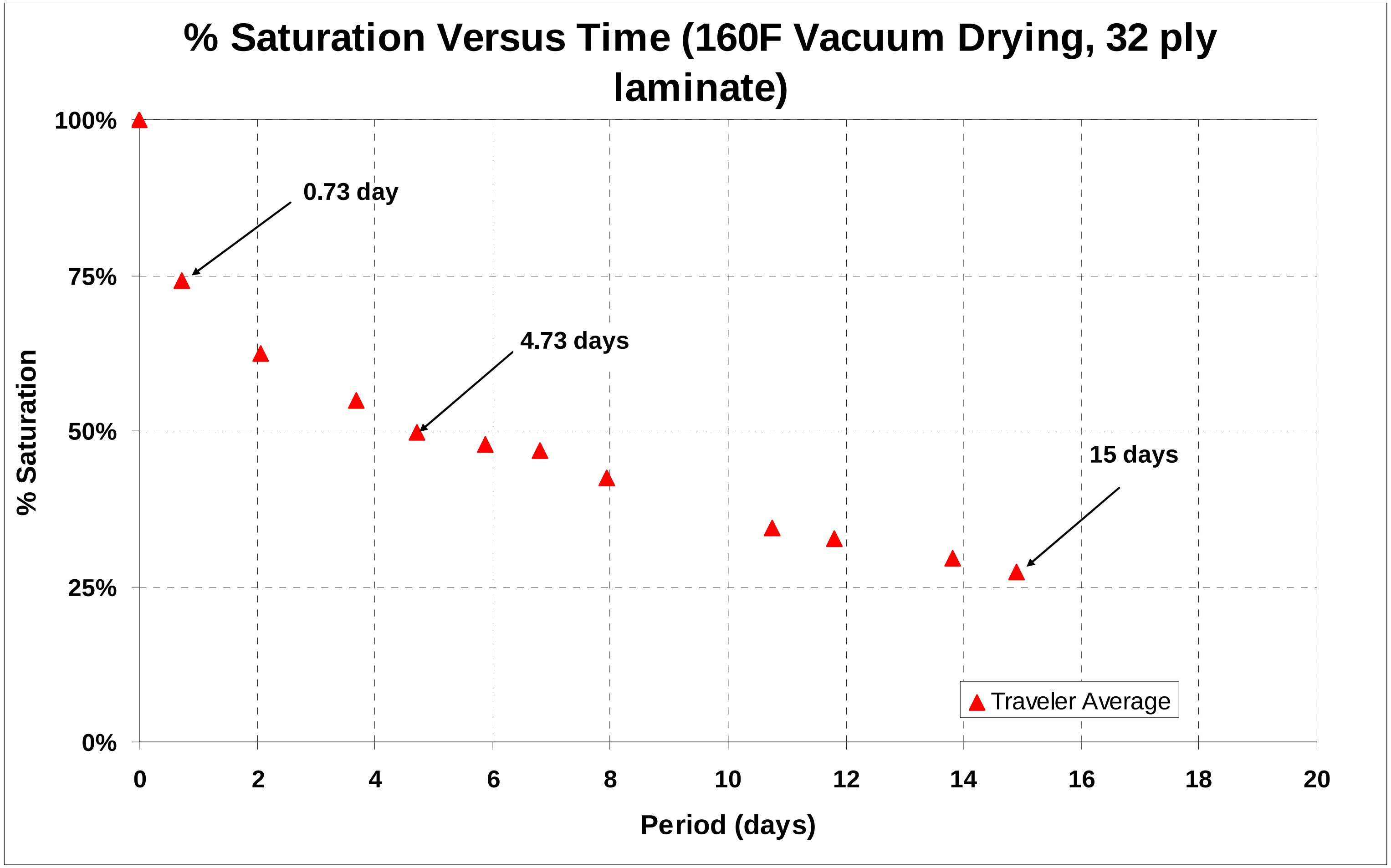
Effects of Contamination



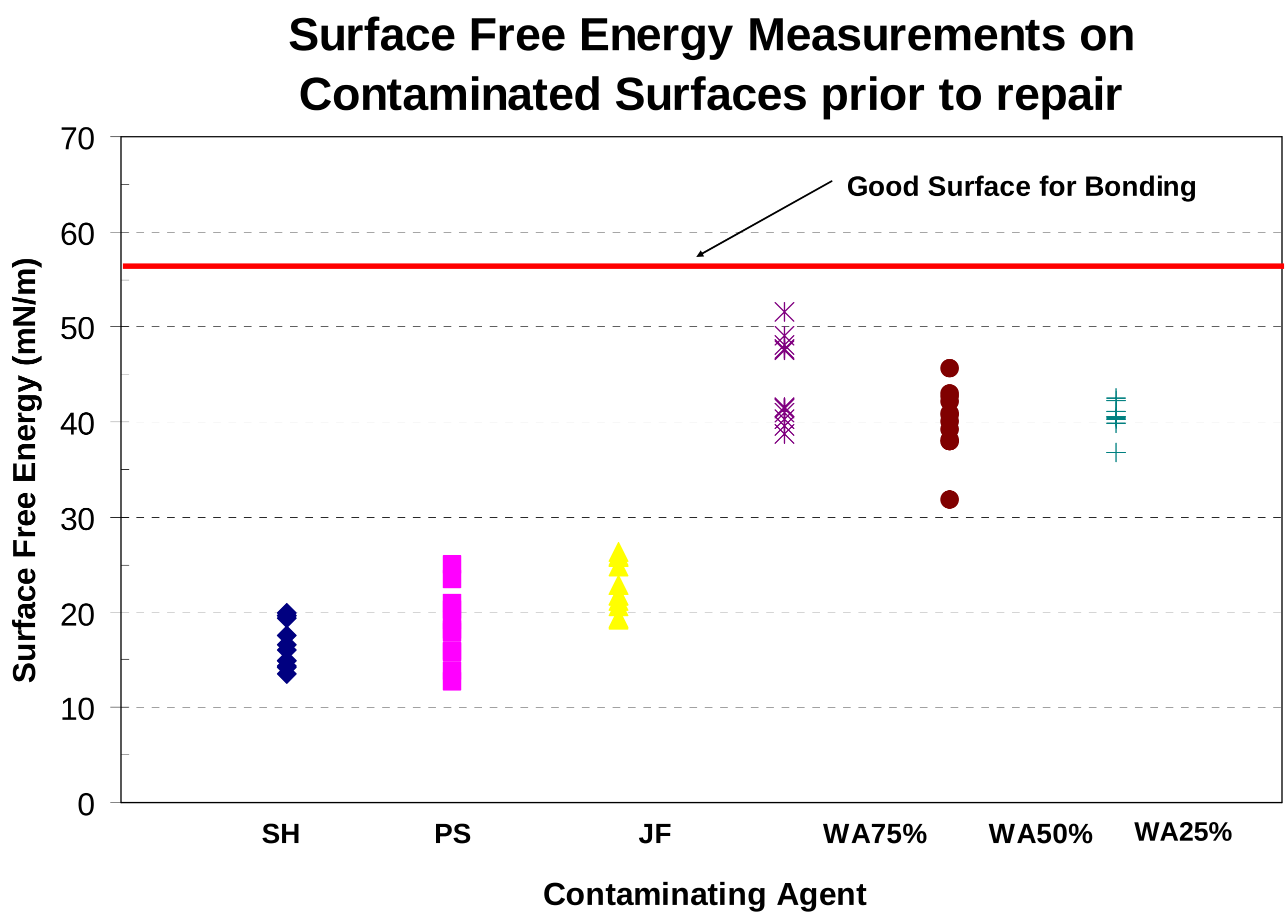
Exposure to Water and Skydrol in progress

Methodology

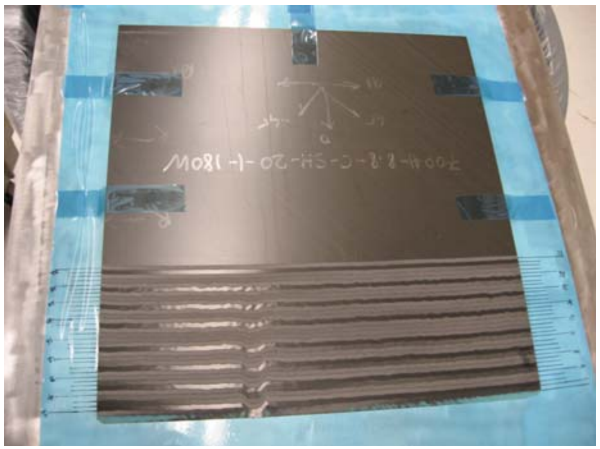
Effects of Contamination



Methodology
Effects of Contamination

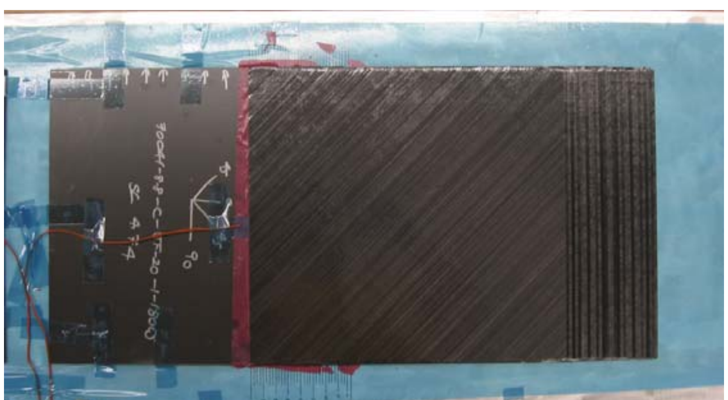


Repair after Contaminant Exposure



Individual Ply Location Marking

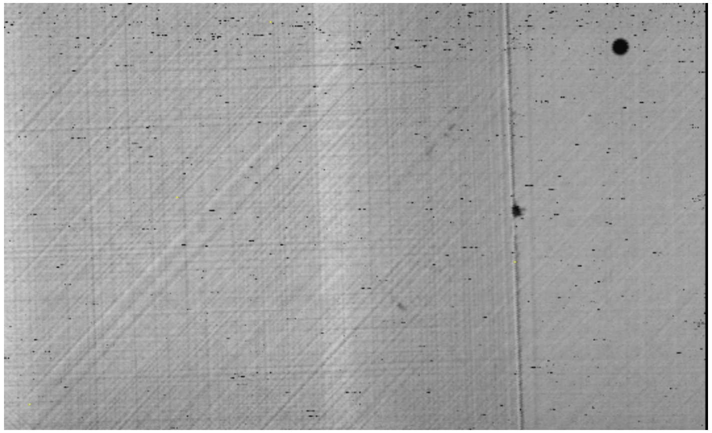
Adhesive Application



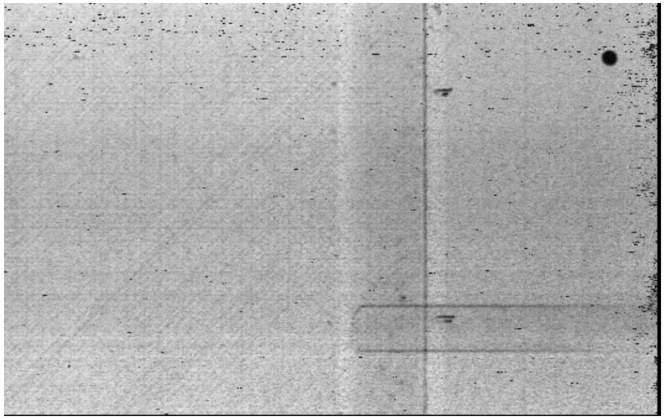
Repair Lay-up/ Thermocouple Installation

Repair Bagging

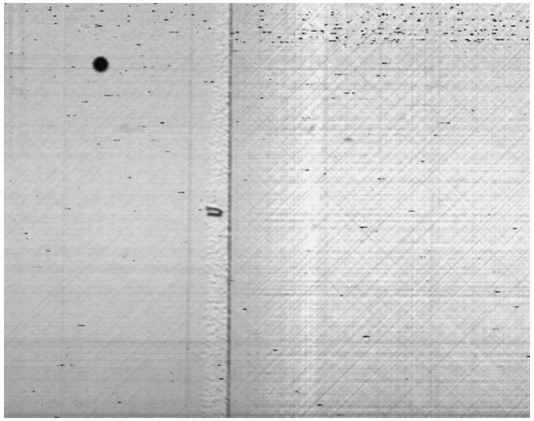
TTU Non-Destructive Inspection



Jet Fuel Contaminated Panel



Skydrol Contaminated Panel



Water Contaminated Panel

Methodology

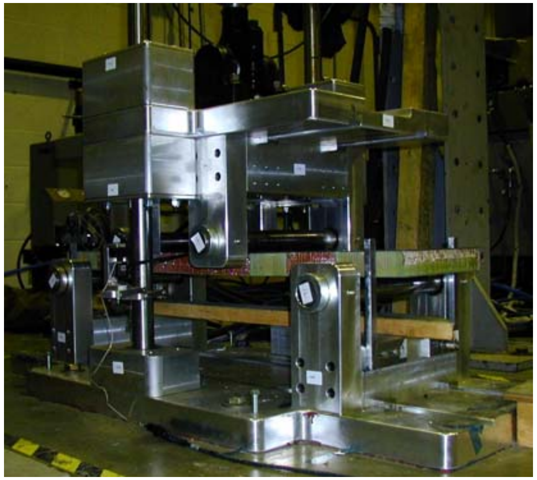
Effects of Contamination

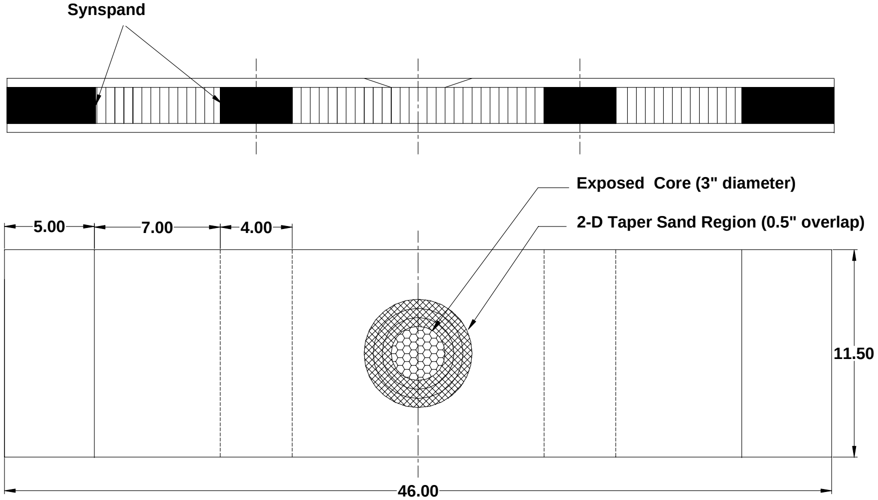
- All Panels have been exposed to water, skydrol, jet fuel and paint stripper
- Contaminated panel inspection (Dr. Stevenson) and repair in progress
- Contaminated panel NDI in progress
- Contaminated coupon tabbing and machining in progress
- Preliminary static data shows a 20% strength degradation for panels with 75% moisture content prior to bonding
- Mechanical testing in progress

Methodology
Sandwich Repair Evaluation

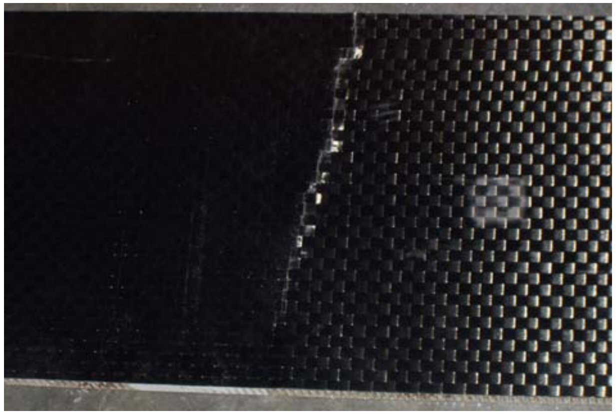
➢ **To evaluate the strength and durability of OEM vs field repairs. Scarf repairs and external patch repairs are considered for this investigation.**

Repair Configuration	Core Cell Size (in)	Repair Material	Repair Type	Scarf Overlap (in)	Static (RTA)	Fatigue (RTA)
2-D Compression Baseline Data	1/8	Toray T700/2510 PW prepreg	Baseline Undamaged Flush Scarf Repair External Patch	 0.5 0.5	6 6 6	6 6 6
	1/8	CACRC Wet lay-Up Repair	Flush Scarf Repair External Patch	0.5 0.5	6 6	6 6
2-D Compression Effects of Cure Cycle Deviations	1/8	Toray T700/2510 PW prepreg	Flush Scarf Repair/ undercure Flush Scarf Repair/ overcure	0.5 0.5	6 6	





Methodology
Sandwich Repair Evaluation

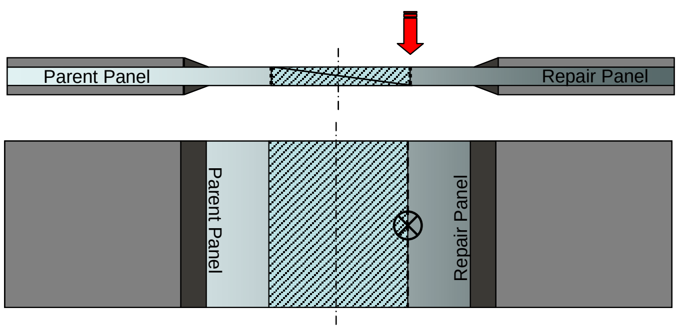


Panel design validated
Screening Panels yielded acceptable failures
Panel Manufacture in progress

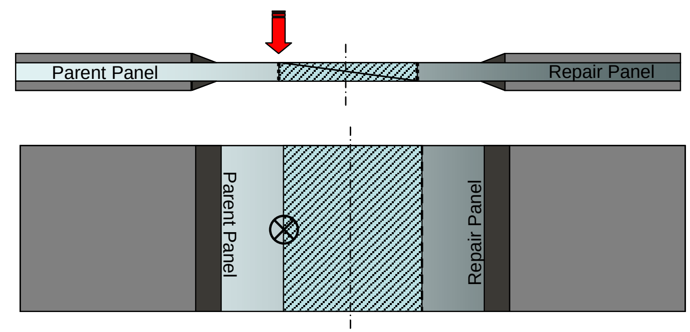
Methodology – Damage Effects

- **To evaluate the strength, durability and damage tolerance of repairs applied to laminate structures. 144 Coupons of different thicknesses and stiffnesses are being considered and are being impacted in three different locations: at the center of the repair scarf and at the edge of the scarf.**

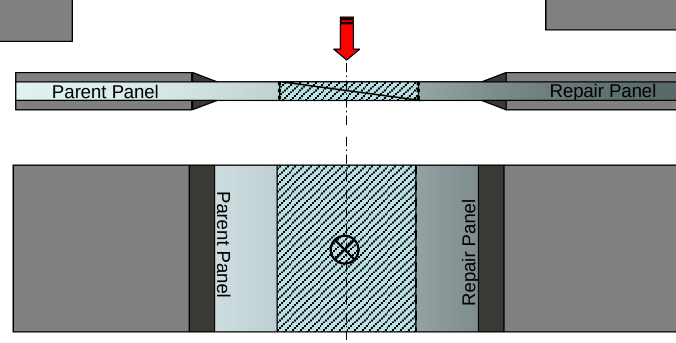
Tip of the scarf far side TF



Tip of the scarf TN



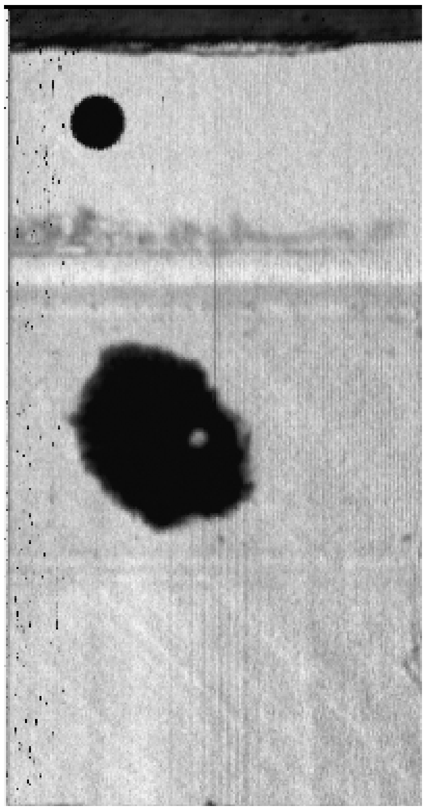
Center Impact



Methodology – Damage Effects

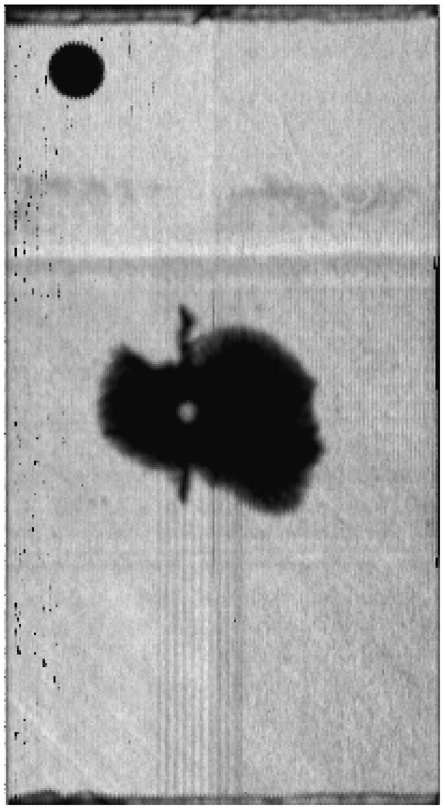
Plies	Modulus	scarf rate	Test Condition	Impact Site TN	TF	CN
18	7.2	10	RTA	3	3	3
			RTF	3	3	3
		20	RTA	3	3	3
			RTF	3	3	3
	9.1	10	RTA	3	3	3
			RTF	3	3	3
		20	RTA	3	3	3
			RTF	3	3	3
48	7.2	10	RTA	3	3	3
			RTF	3	3	3
		20	RTA	3	3	3
			RTF	3	3	3
	9.1	10	RTA	3	3	3
			RTF	3	3	3
		20	RTA	3	3	3
			RTF	3	3	3

Methodology – Damage Effects



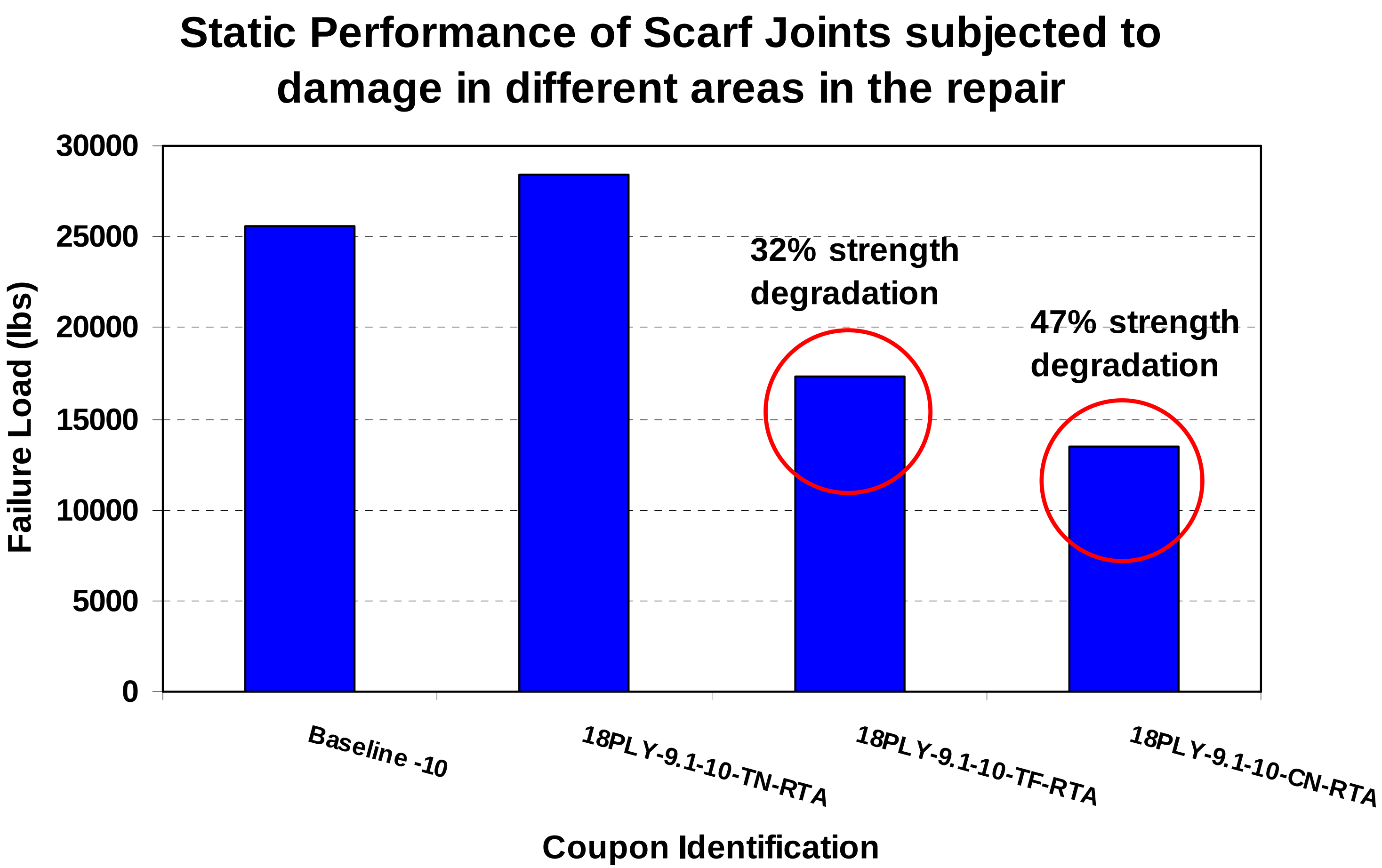
10941-18-7.2-20-CN-180W-1

10941-18-7.2-20-CN-180W-2

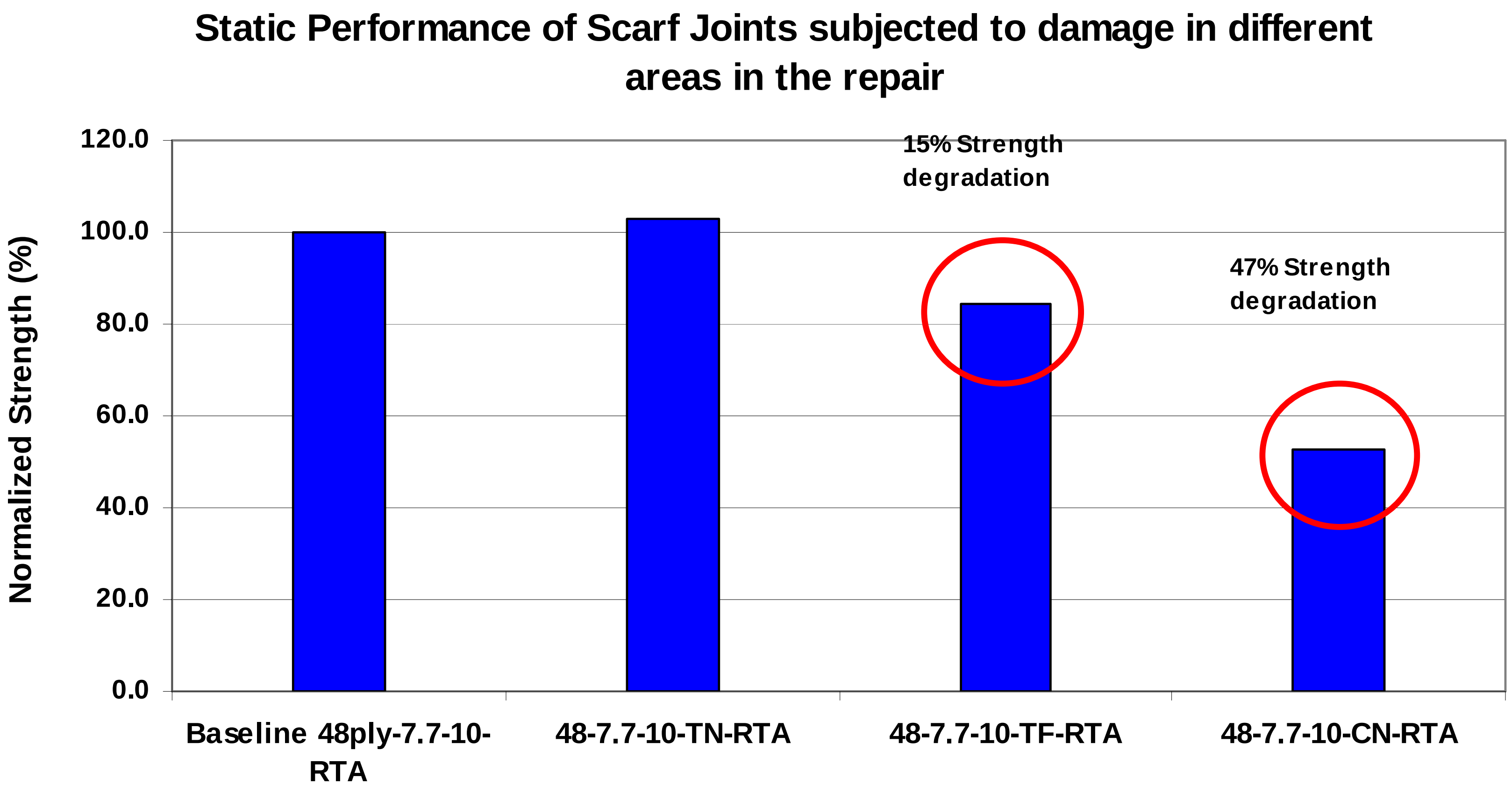


10941-18-7.2-20-CN-180W-3

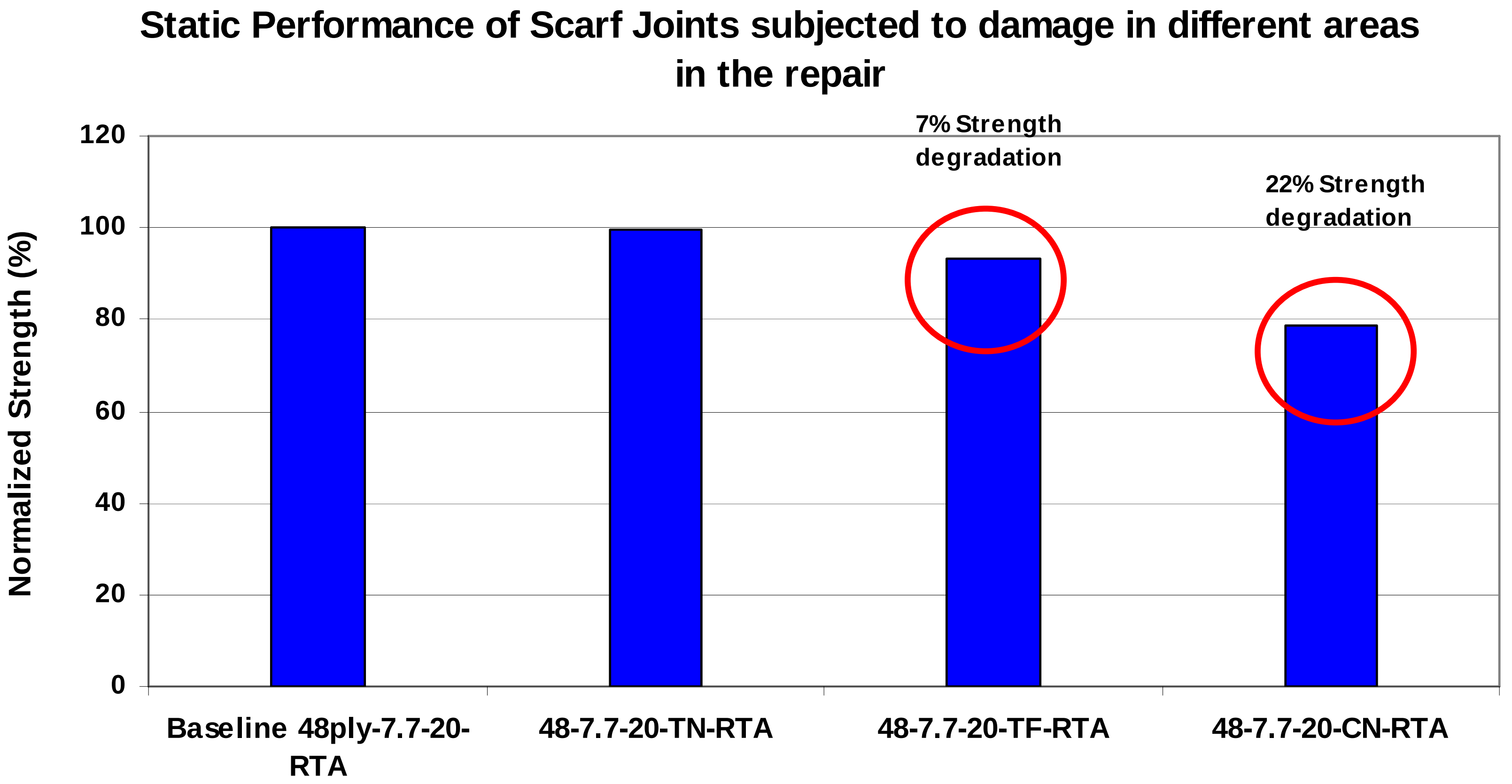
Methodology – Damage Effects



Methodology – Damage Effects



Methodology – Damage Effects



Methodology
Damage Effects Summary

- Strength degradation is proportional to damage area
- Coupons impacted at the center of the repair, had the largest damage area and the lowest static strength
- The performance of coupons impacted at the edge of the repair was comparable to that of baseline repaired undamaged coupons
- The residual strength is also dependent on the “residual” bond area. The largest repairs are more “damage tolerant” than smaller repairs

Status to Date
Deliverables

- Baseline Laminate OEM Repair Data – Complete
- Baseline Laminate Field Repair Data (T800/ MTM45-1) – Complete
- Laminate Contamination/ effects of process parameter investigation – In Progress
- Laminate Damage tolerance investigation – Complete
- Baseline Sandwich OEM/CACRC Repair Data – In Progress

- All Laminate testing to be completed by July 07
- All Sandwich testing to be completed by September 07
- FAA Report to be submitted on December 07

A Look Forward/ Future Plans

Benefits To Aviation:

- To generate repair data for OEM/ factory materials that can be used to demonstrate acceptability of alternate materials to use for repair when the parent material is not available or cannot be used for repair
- To generate data that correlates contamination and process parameter deviation to the performance of bonded repairs
- To provide information on repair damage tolerance depending on the area where the damage was inflicted
- To identify the crucial steps in bonded repair
- To develop rigorous repeatable repair processes that ensure structural integrity of bonded repairs
- To gain confidence in bonded structural repairs