Bonded Repair of Composite Airframe Laminate and Sandwich Structures

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Presented at the CACRC meeting, November 16th 2007

Objective

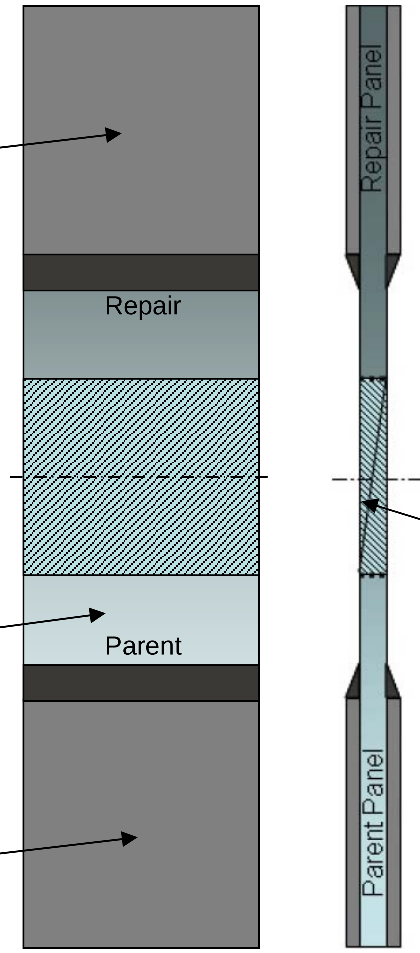
To investigate different variables on the performance of repairs applied to solid laminates and sandwich structures

- **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 damage tolerance of repairs subjected to BVID inflicted at three different locations on the repair (Laminate)**
- **To provide recommendations pertaining to process improvement to ensure repair bond repeatability and structural integrity**

Laminate Repair Coupon Configuration

Fiberglass Tabs

Single scarf joint, 4” wide to isolate the variables investigated



Adhesive Layer Metalbond 1515 or FM300-2

Parent Toray T800/3900 graphite epoxy

Fiberglass Tabs

Methodology
OEM Repair Material Evaluation

- **To generate baseline repair data with the parent material (T800/3900) used as the repair material (OEM repair), 96 coupons used for the investigation**

- **18, 32 ply**
- **Moduli**
- **Scarf rates**
- **Static/ fatigue performance**

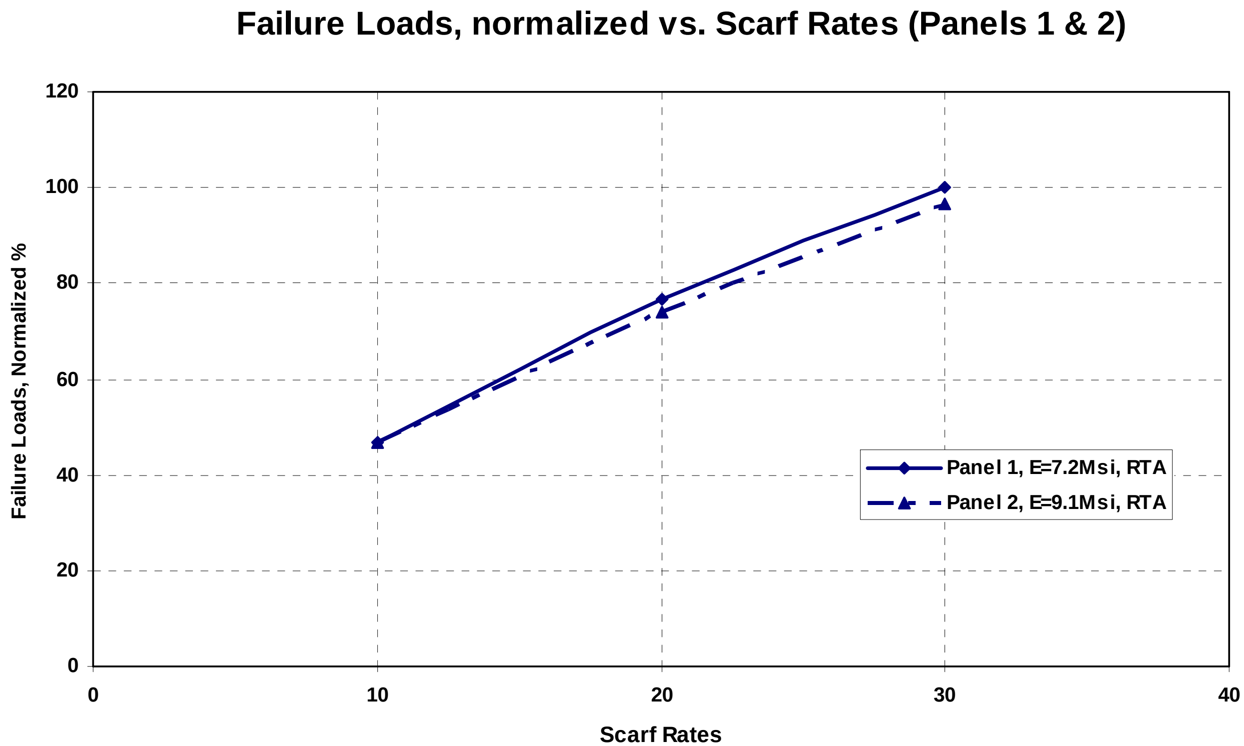
				STATIC	FATIGUE
Panel #	**Thickness (in)**	**E (Msi)**	**Scarf Rate**	RTA	RTA
1	0.1332	7.2	10	6	3
			20	6	3
			30	3	3
2		9.1	10	6	3
			20	6	3
			30	3	3
3	0.2368	7.7	10	6	3
			20	6	3
			30	3	3
4		8.8	10	6	3
			20	6	3
			30	3	3

Methodology
OEM Repair Material Evaluation- Results

100% corresponds to the failure load of the -30 repairs

increased load carrying capability with increased repair size

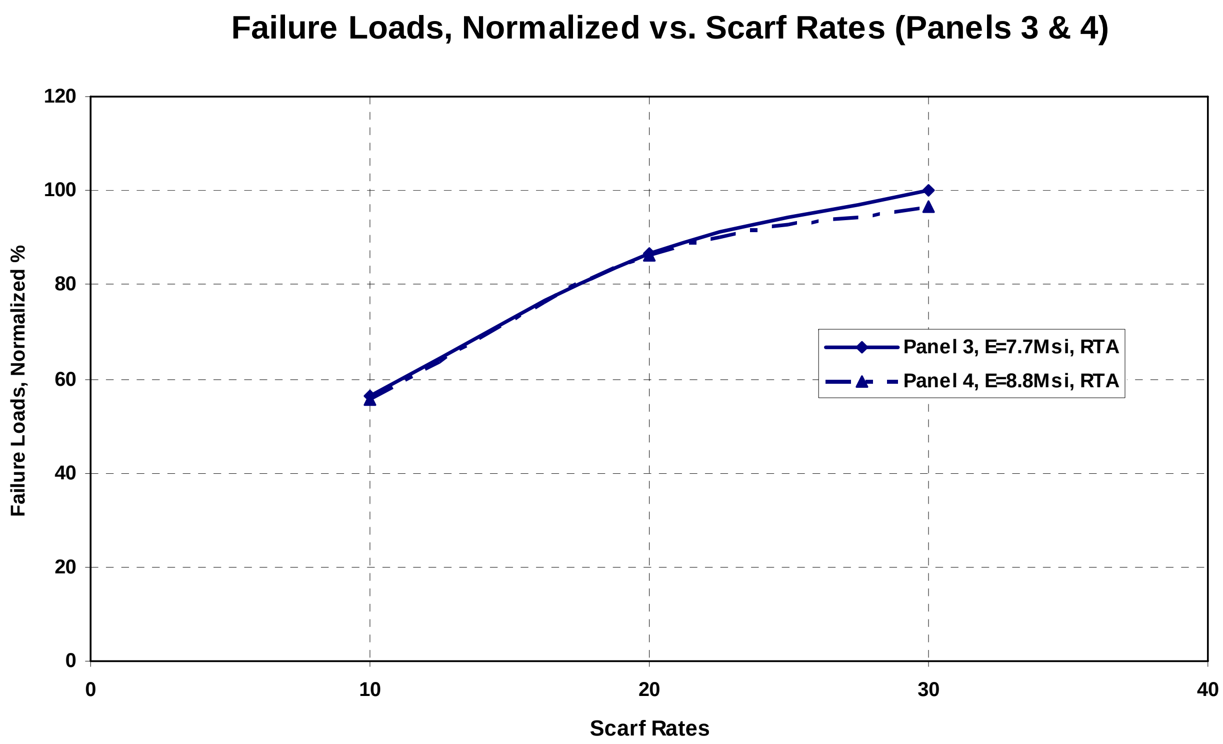
comparable performance for both panels



Methodology
OEM Repair Material Evaluation-Results

100% corresponds to the failure load of the -30 repairs

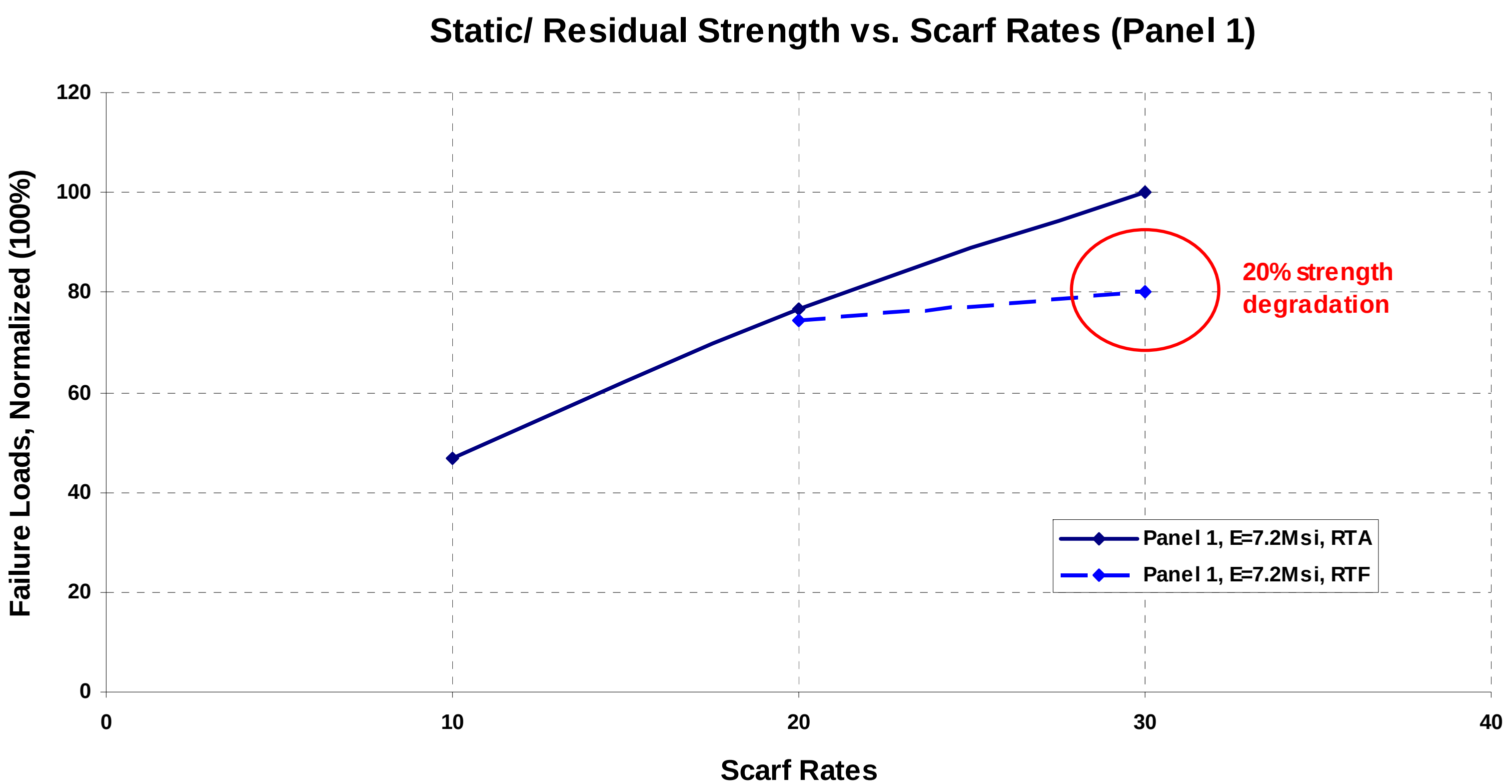
increased load carrying capability with increased repair size (32 ply)



Methodology
OEM Repair Material Evaluation

100% corresponds to the failure load of the -30 repairs

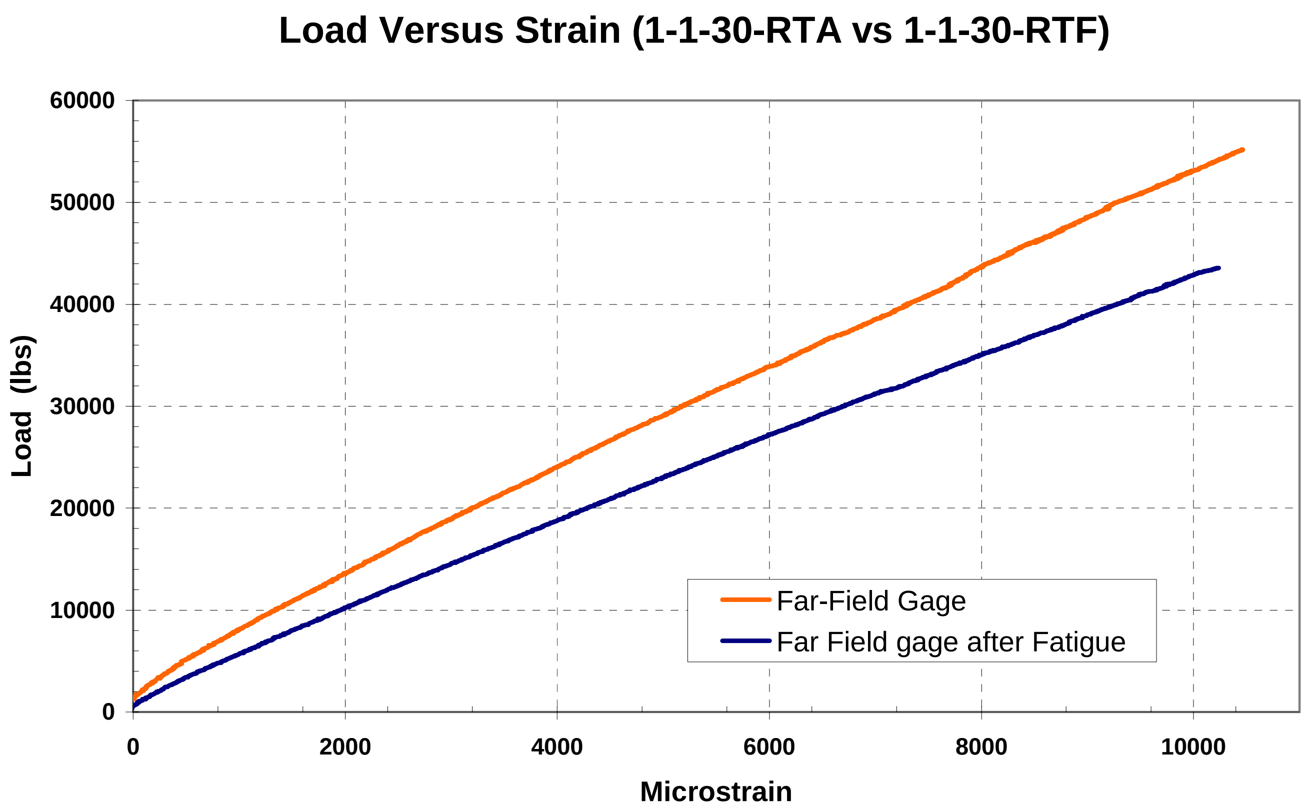
comparison of the RS after fatigue to the static strength



Methodology
OEM Repair Material Evaluation

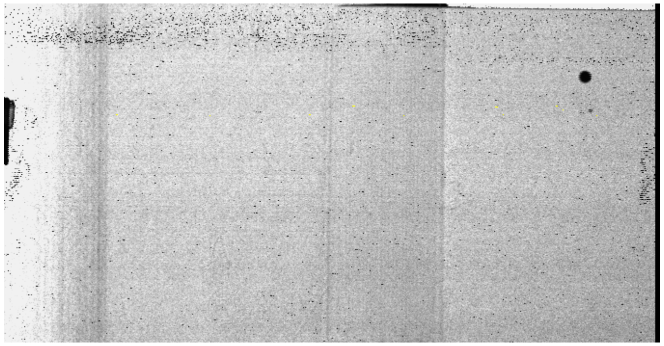
Load vs strain for static and residual strength coupon

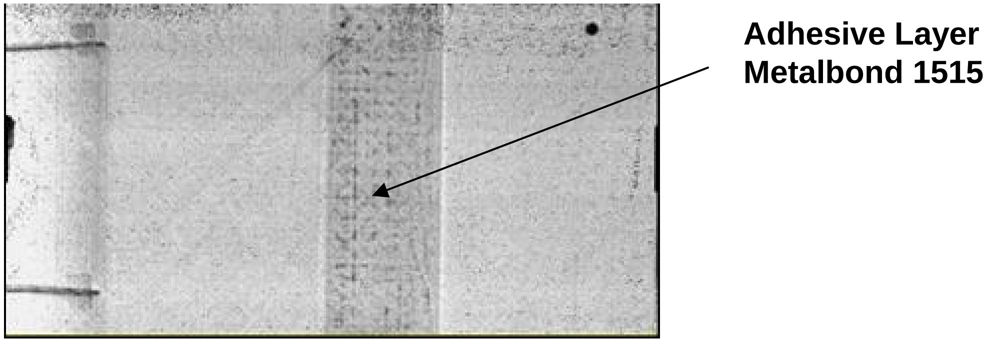
Stiffness loss after fatigue



Methodology
OEM Repair Material Evaluation

- Bonded Repair performance is dependent on variability in repair process
- Overall increas in 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 18ply panels residual strength after fatigue was 20% lower than their ultimate static strength capability due to a change in compliance/ stiffness after fatigue (adhesive plastic deformation)





Methodology
Field Repair Material Evaluation

- To generate baseline repair data for a candidate field repair material (ACG T800/ MTM45-1, 250°F vacuum cure system), 72 coupons used for this investigation (scarf rates correspond to 5.7°, 2.86° and 1.98°)

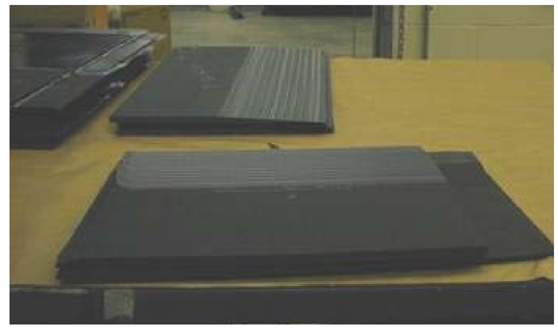
- 18, 32 ply
- Moduli
- Scarf rates
- Static/ fatigue performance

				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

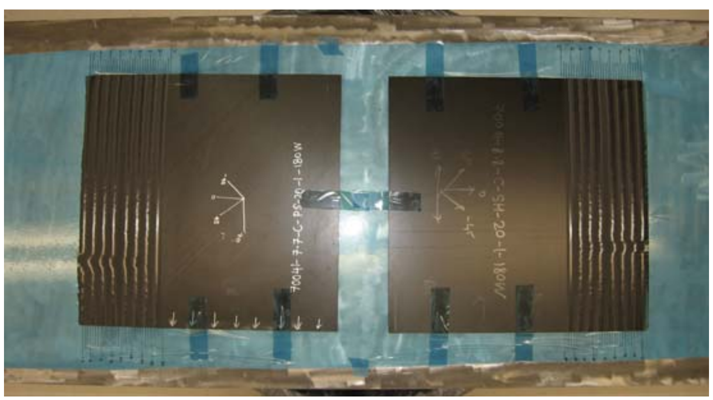
Methodology
Field Repair Material Evaluation

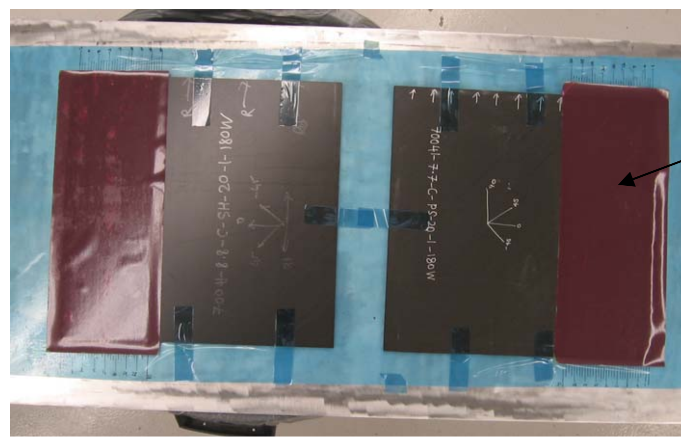
Panel preparation, Repair Procedure Details

Scarf Machining



Scarfed Panels



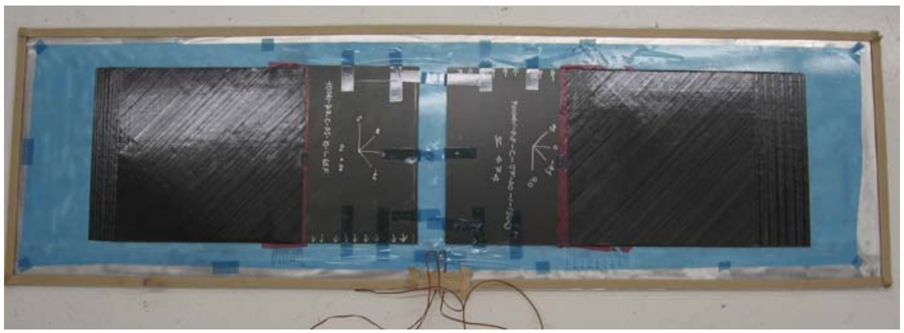


Adhesive Layer FM300-2

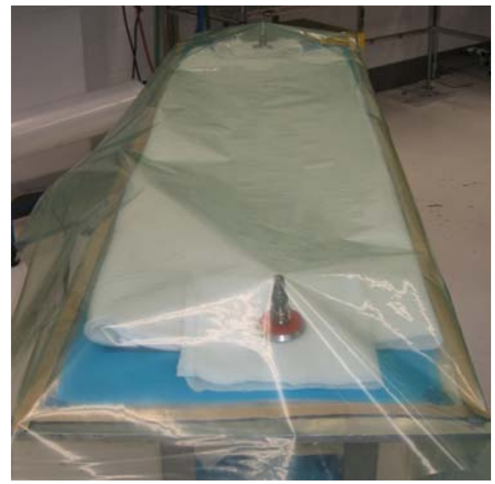
Repair Implementation

Methodology
Field Repair Material Evaluation

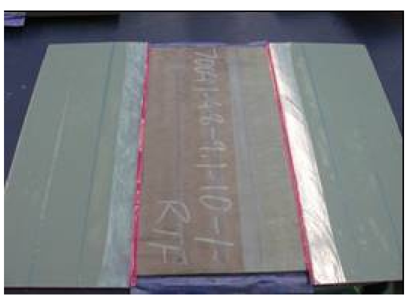
Repair ply lay-up following edge markings



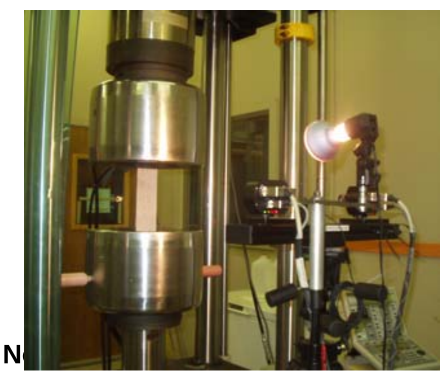
Repair Implementation



Repair Bagging/ Curing

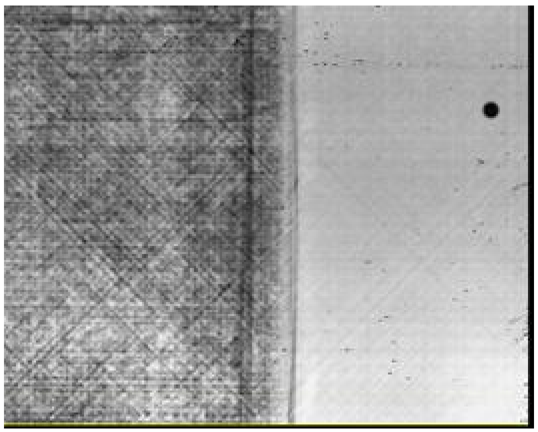


Tabbed Panel

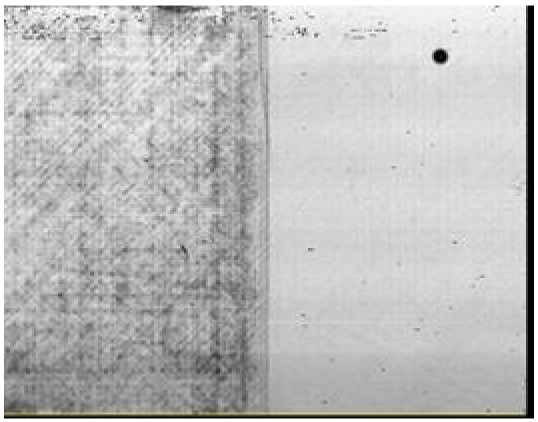


Mechanical Testing

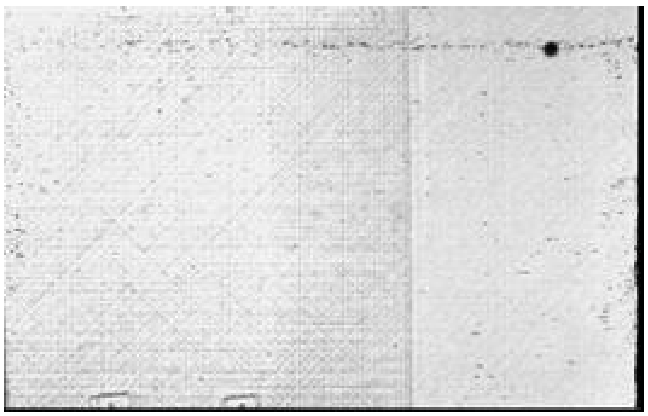
Methodology
Field Repair Material Evaluation



ACG 2-1-10-RTA



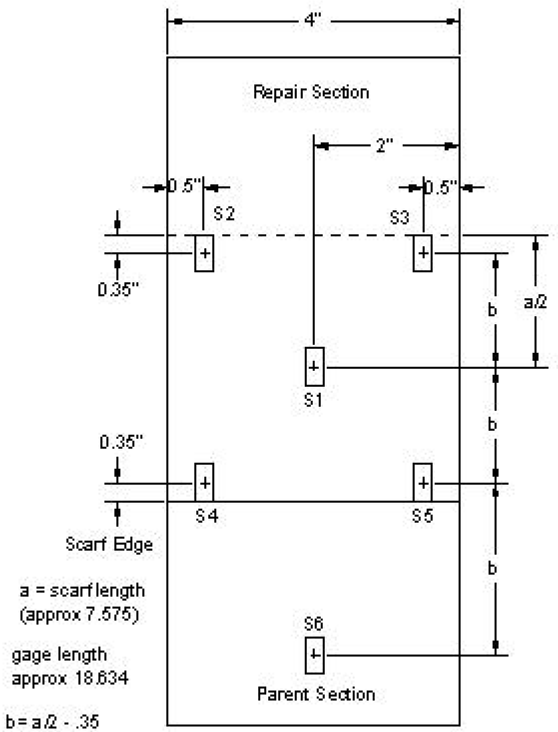
ACG 2-1-10-RTF



4-2-20-RTA

- Process yielded repairs with various levels of porosity as illustrated by the C-Scan images
  Possible source of variability in the mechanical data

Results
Field Repair Material Evaluation



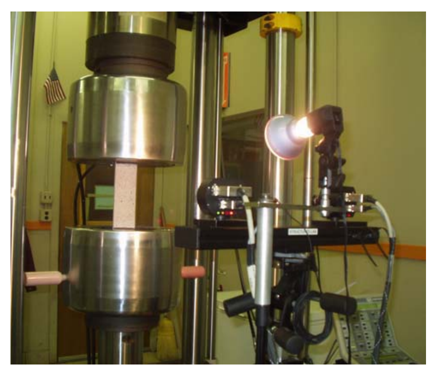
- **ARAMIS**

a non-contact optical 3-D deformation measuring system that uses two high resolution cameras to monitor strain concentrations in a test article

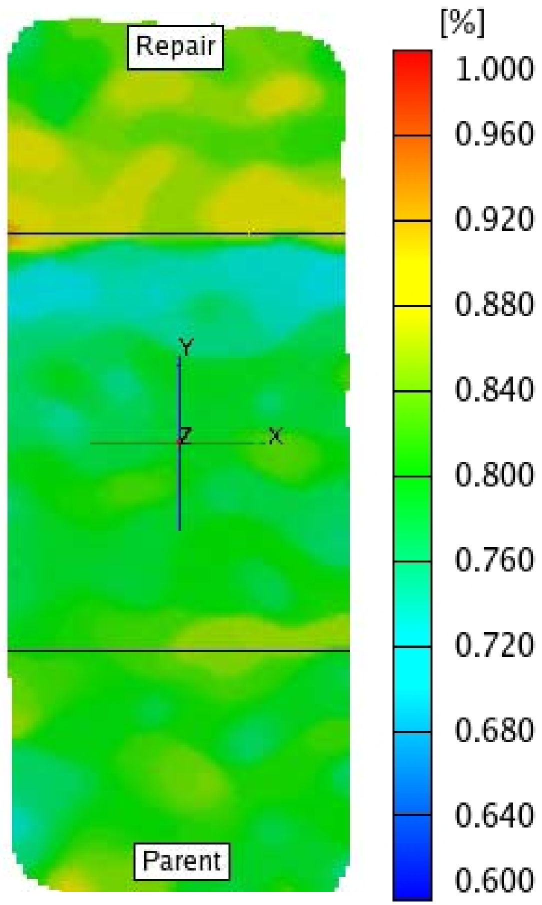
the test article is sprayed with a random pattern prior to loading

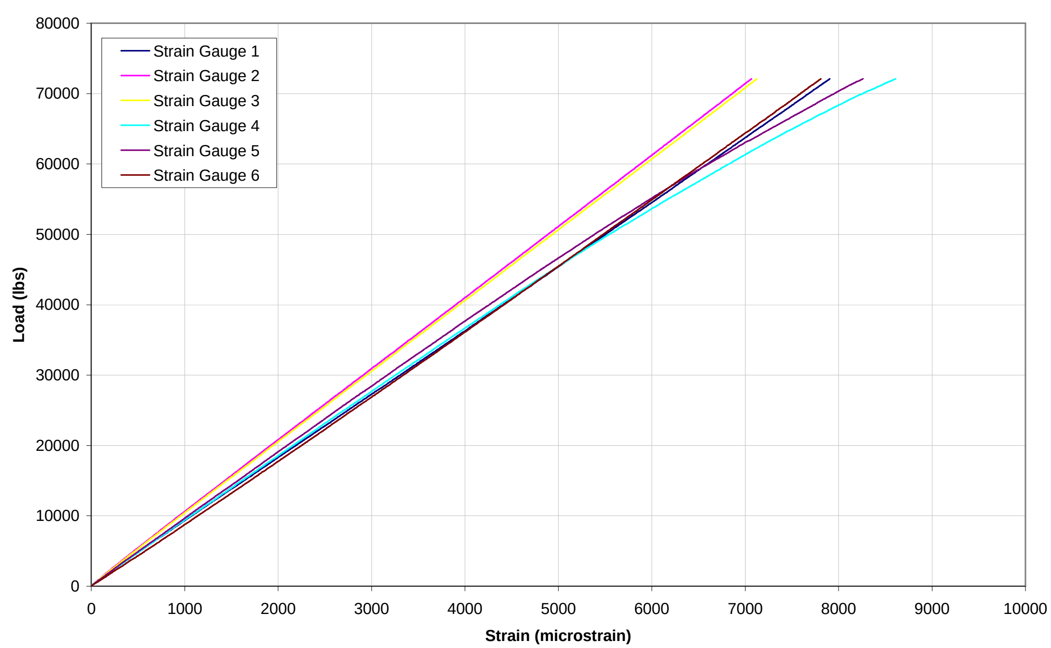
measurements are taken at different load levels,

changes in displacements and rotations between stages are recorded, from which strains can be calculated



Results
Field Repair Material Evaluation

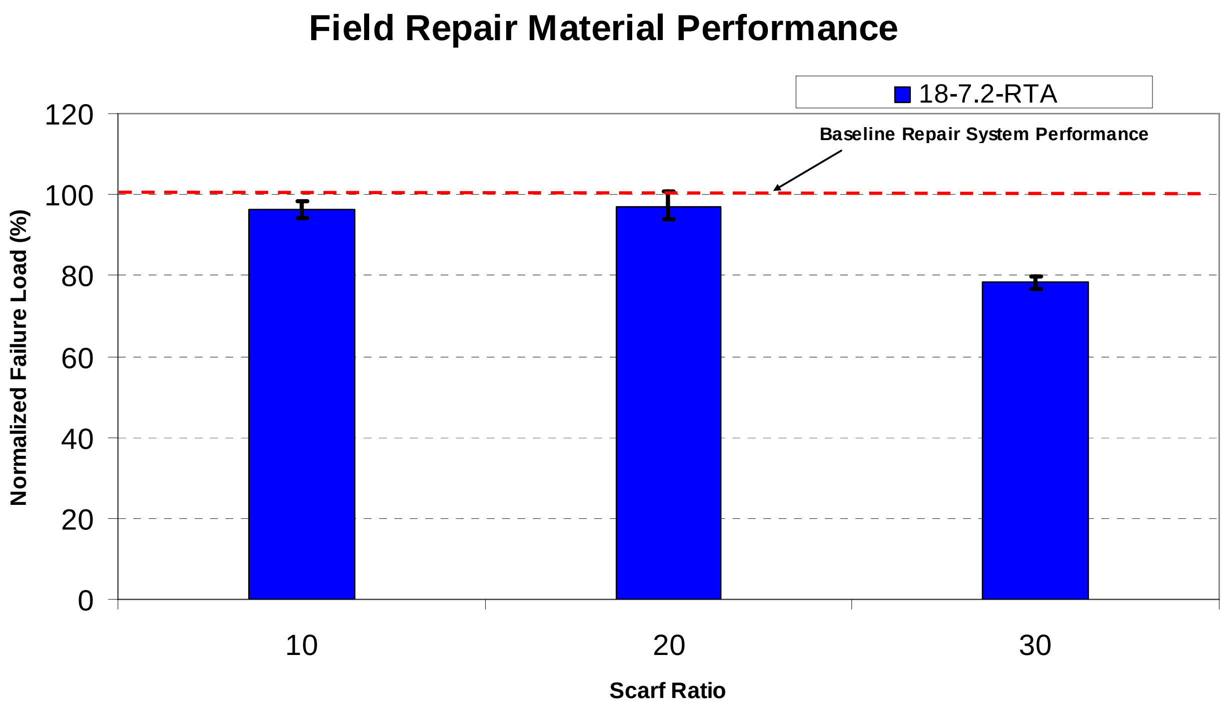




Y-Strain Distribution for ACG-4-2-20-RTA-01

Results-Static
Field Repair Material Evaluation

- Comparison of static strength of the field repairs wrt OEM repairs
- 100% represents the failure load of the baseline repairs (parent material same as repair material)
- At least 80% "baseline repair performance" was restored at room temperature
- Variability (process, bondline thickness)



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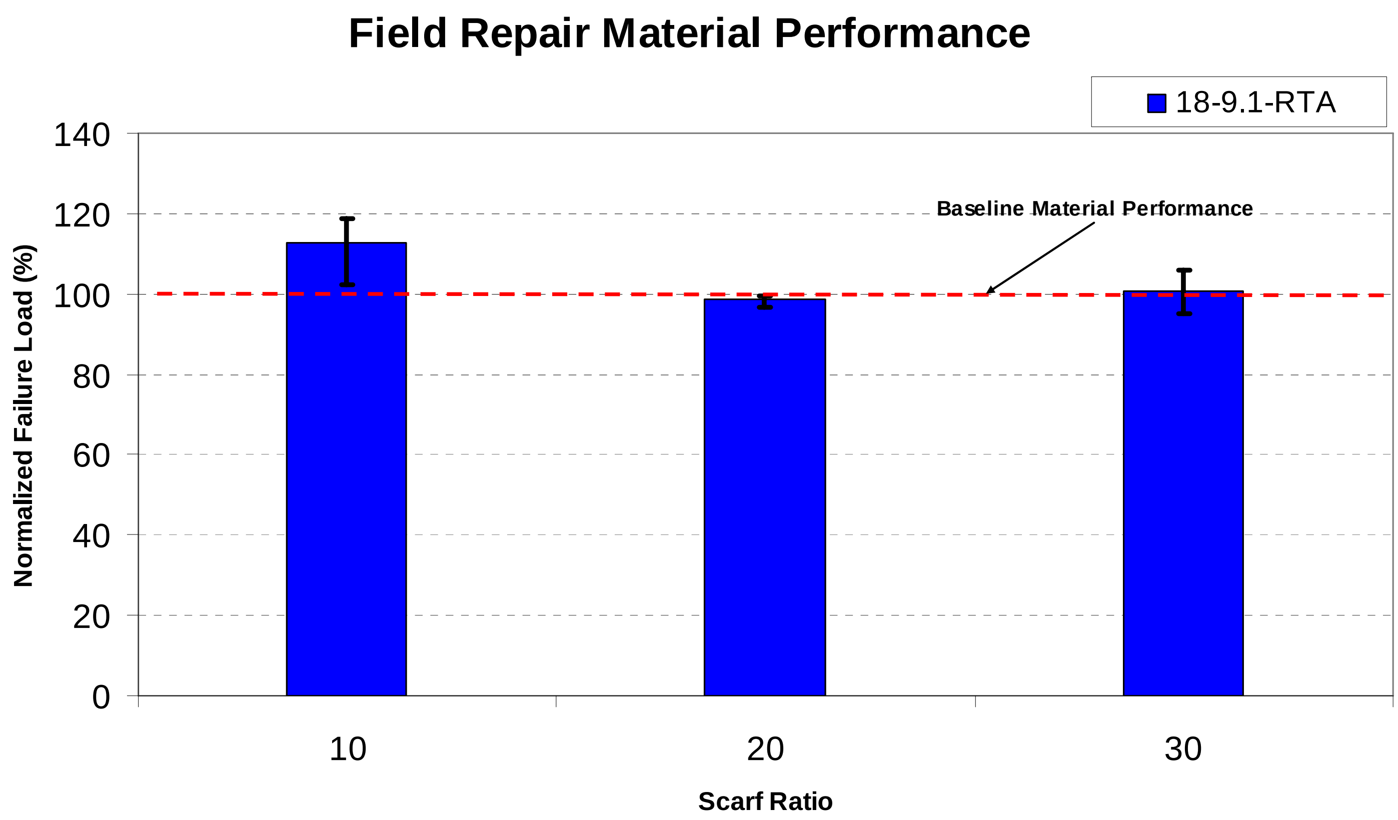
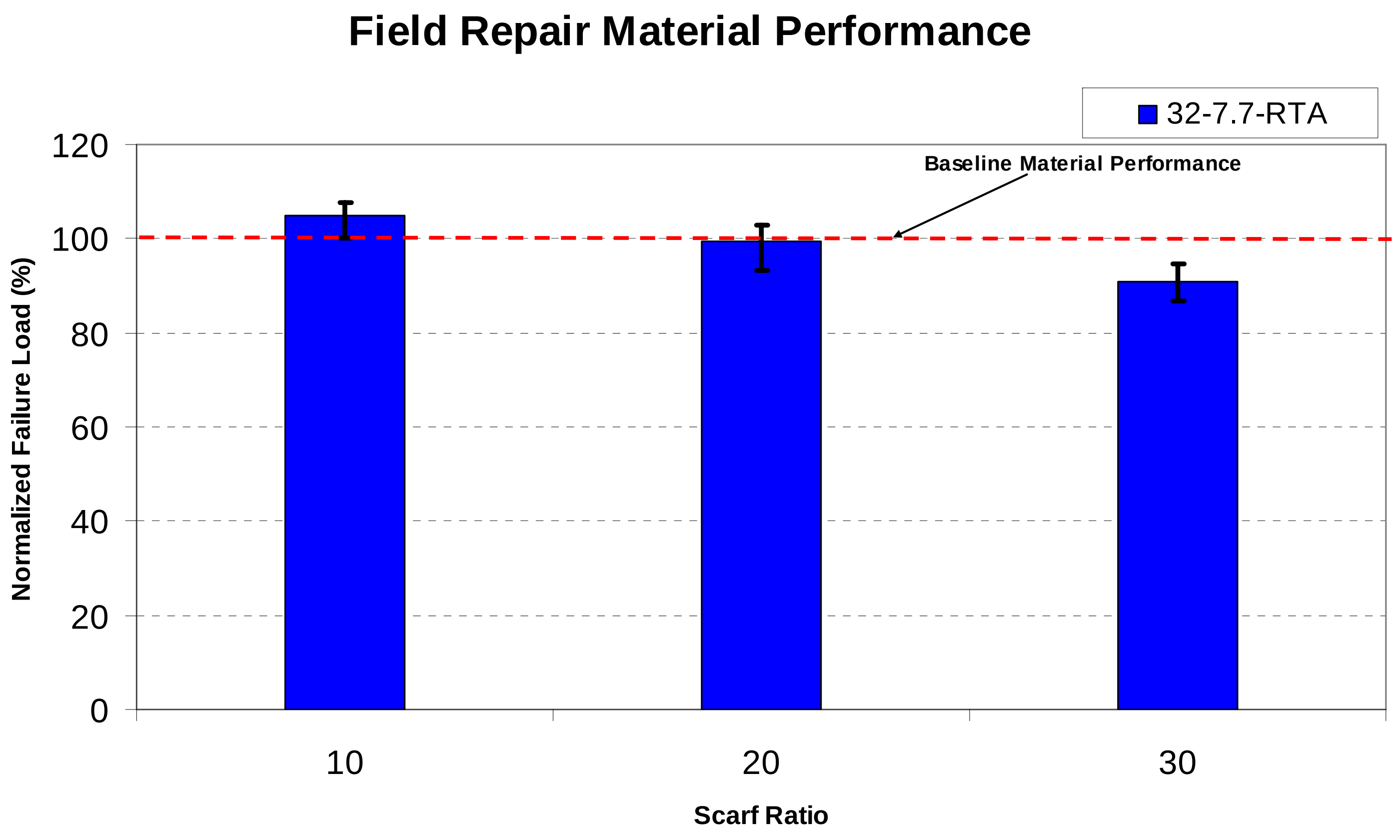
Results-Static
Field Repair Material Evaluation

- Comparison of static strength of the field repairs wrt OEM repairs
- At least 98% “baseline repair performance” was restored at room temperature



Results-Static
Field Repair Material Evaluation

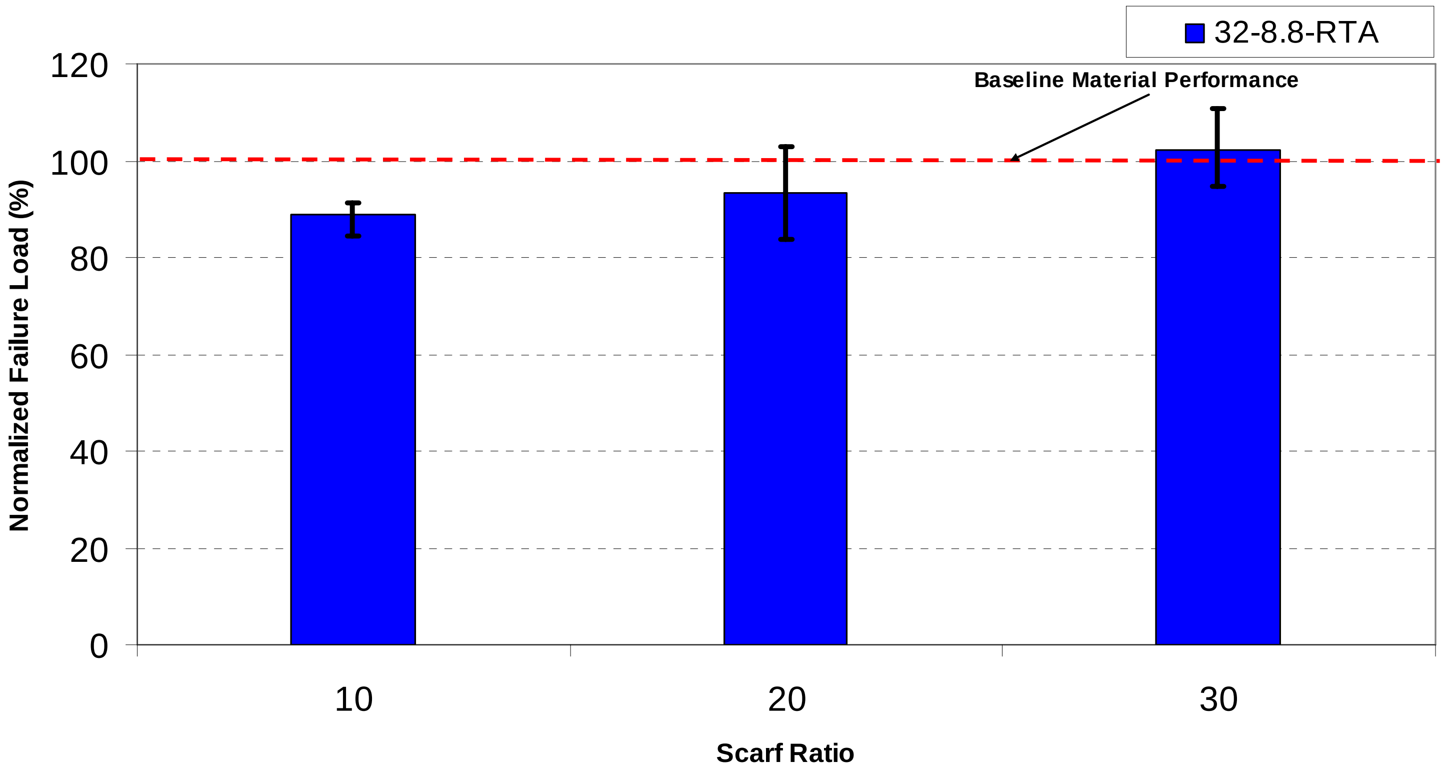
- Comparison of static strength of the field repairs wrt OEM repairs
- At least 90% “baseline repair performance” was restored at room temperature



Results-Static
Field Repair Material Evaluation

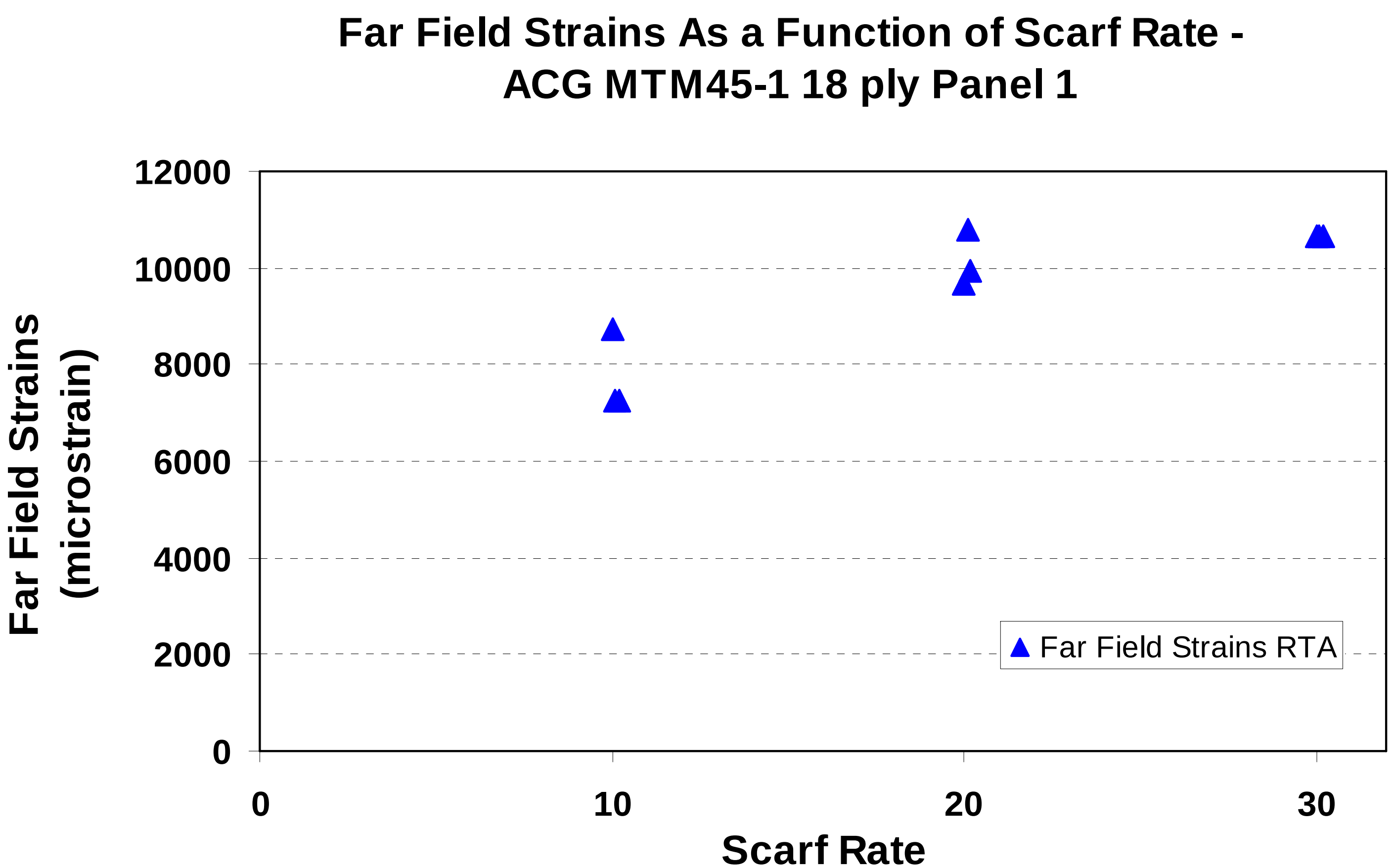
- Comparison of static strength of the field repairs wrt OEM repairs
- At least 89% “baseline repair performance” was restored at room temperature

Field Repair Material Performance



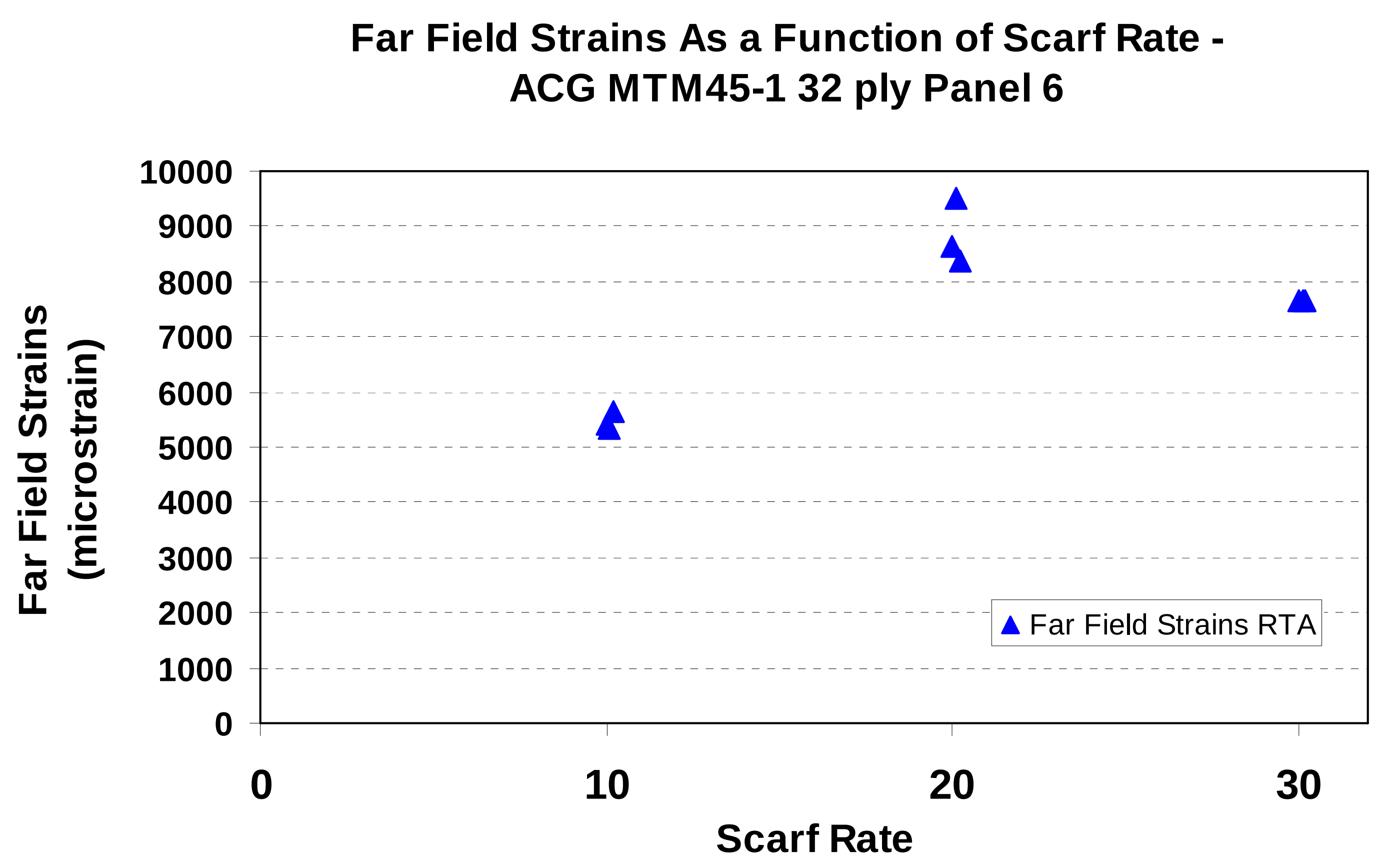
Results-Static
Field Repair Material Evaluation

- Substrate ultimate strain as a function of repair size



Results-Static
Field Repair Material Evaluation

- Substrate ultimate strain as a function of repair size



Methodology - Field Repair Material Evaluation- Summary

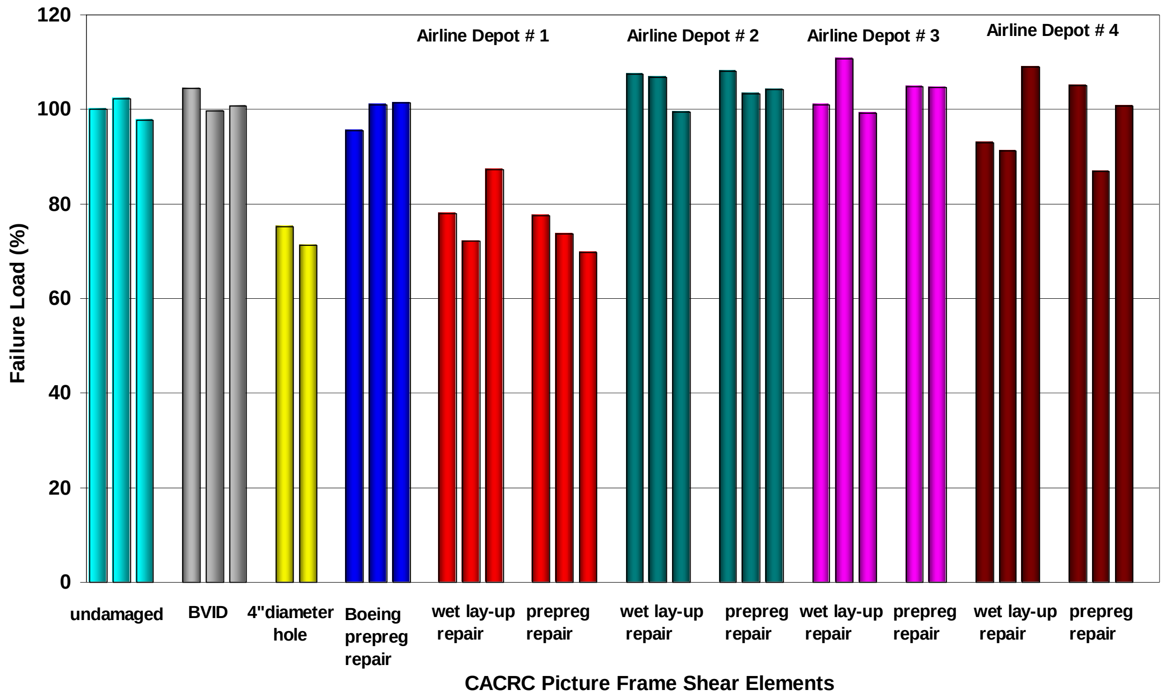
- Field repair material cured at 250°F under vacuum
- At least 89% of RTA baseline joint strength was restored for most cases
- A few low data points (porosity, process variability)
- A higher strength knockdown with respect to baseline repair material performance was observed for CTD and ETW specimens
- The thicker specimens 32 ply repairs survived 3DSO in fatigue for all RTD specimens
- For the 18 ply repairs, the -30 all survived 3DSO (165000) in fatigue at RTA

Methodology
Effects of Contamination

- 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
- Summary of previous FAA/WSU repair study, PFS elements where sent for repair to various airline depots using the same procedures (OEM/ CACRC)

25% strength degradation for repairs performed by airline depot 1

Heat blanket failure



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 and perspiration. 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.

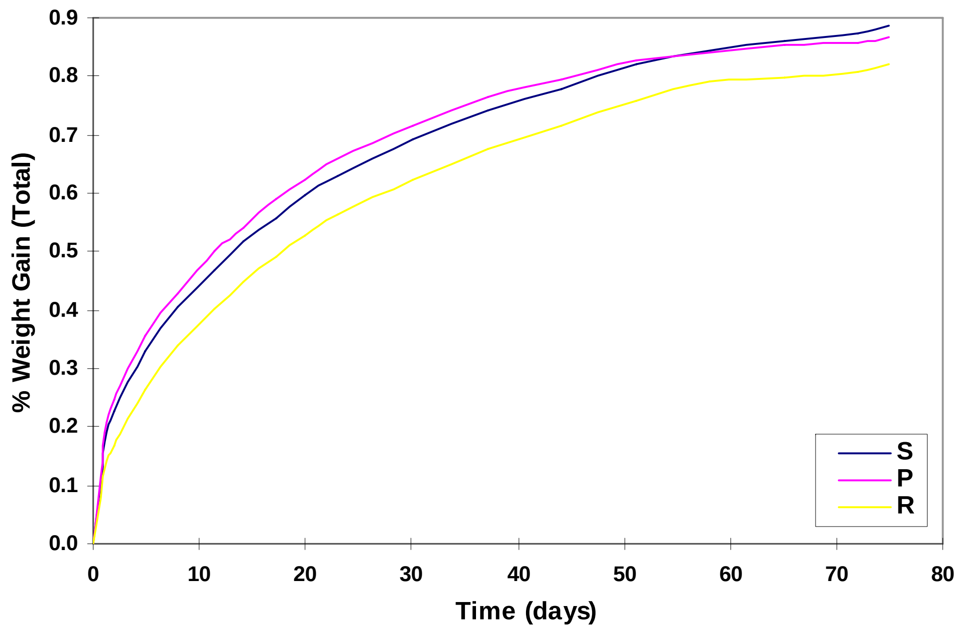
Modulus	scarf rate	Test Condition	Contamination													
			Skydrol		Jet Fuel		Paint Stripper		Water							
									75%		50%		25%		0%	
7.7	10	RTA	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	20	RTA	3	3	3	3	3	3	3	3	3	3	3	3	3	3
8.8	10	RTA	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	20	RTA	3	3	3	3	3	3	3	3	3	3	3	3	3	3

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 have been dried to achieve saturation levels of 0%,25%, 50%, 75% and 100%

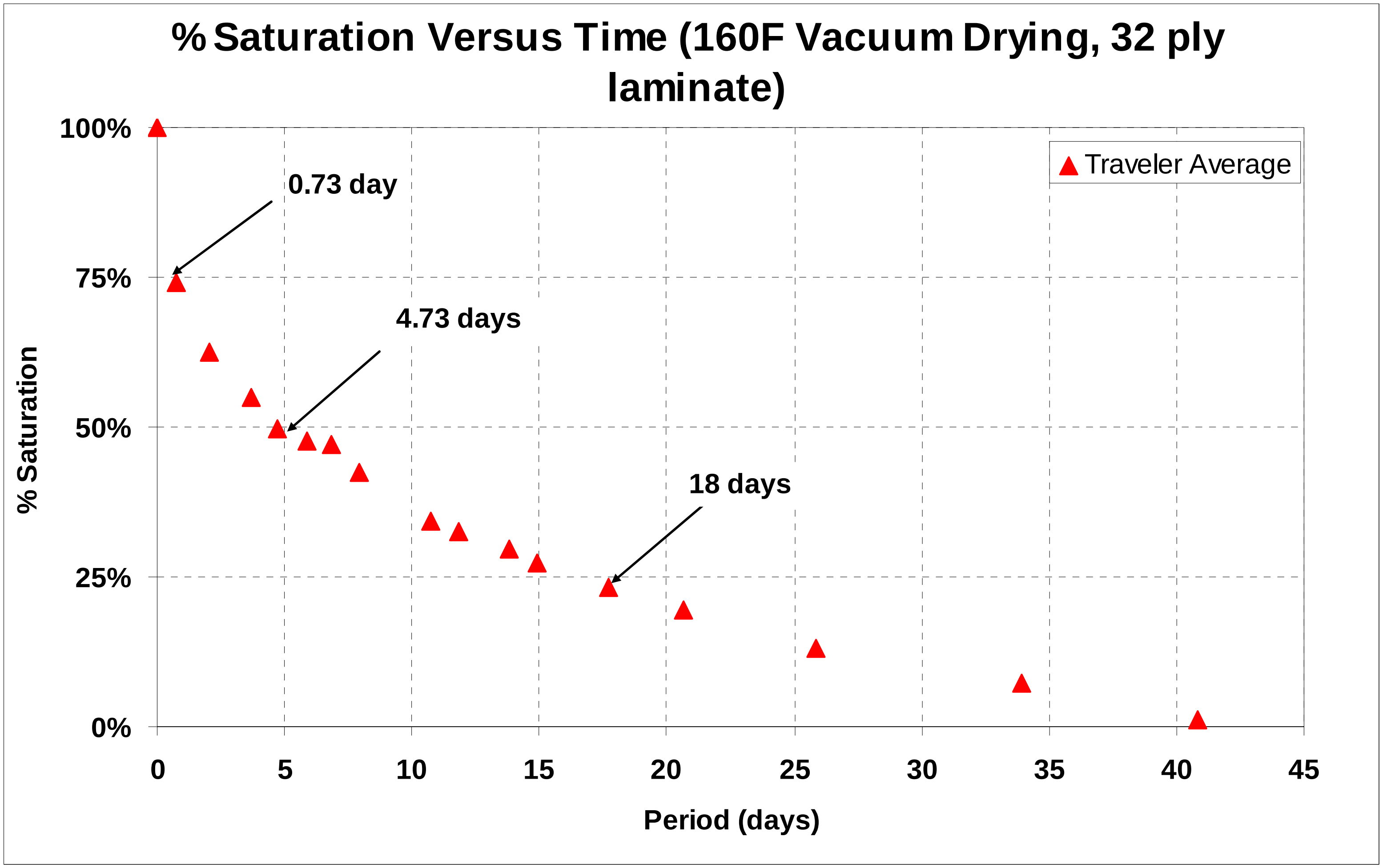
Methodology

Effects of Contamination

Exposure to Water and Skydrol

Methodology

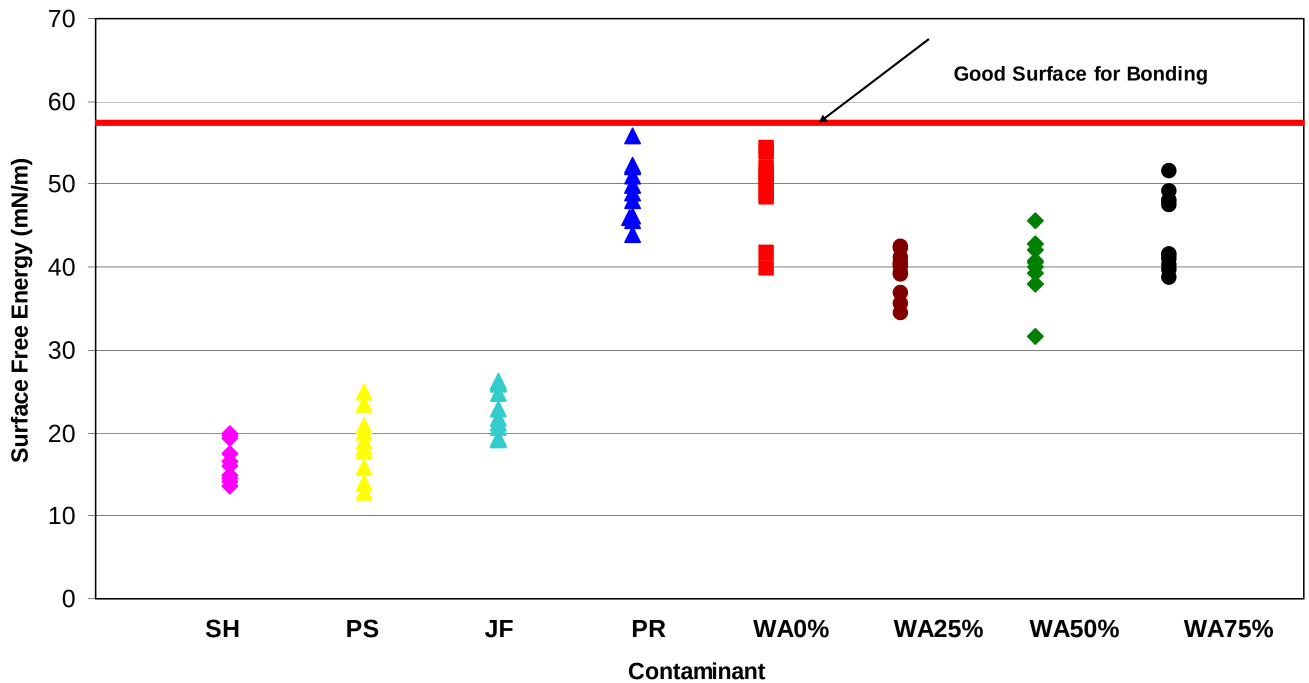
Effects of Contamination



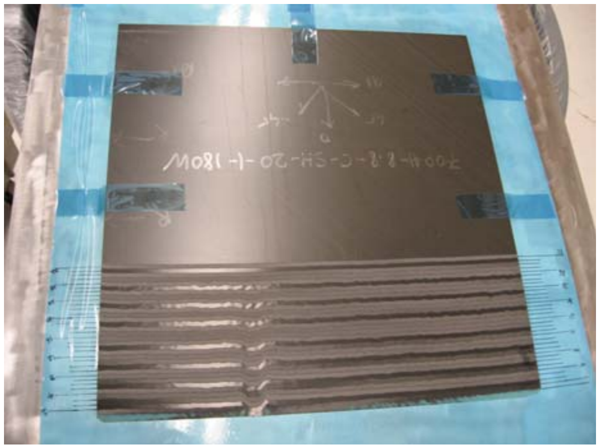
Methodology
Effects of Contamination

Surface Analysis: Dr Stevenson/ Irish Alcalen

Surface Free Energy Measurements for Contaminated Surfaces prior to Repair

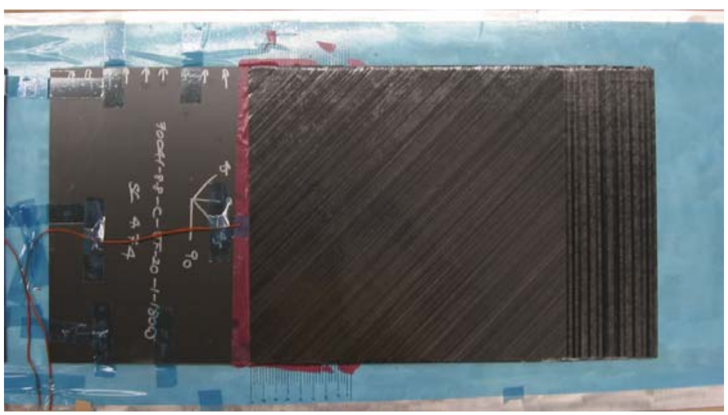


Repair after Contaminant Exposure



Individual Ply Location Marking

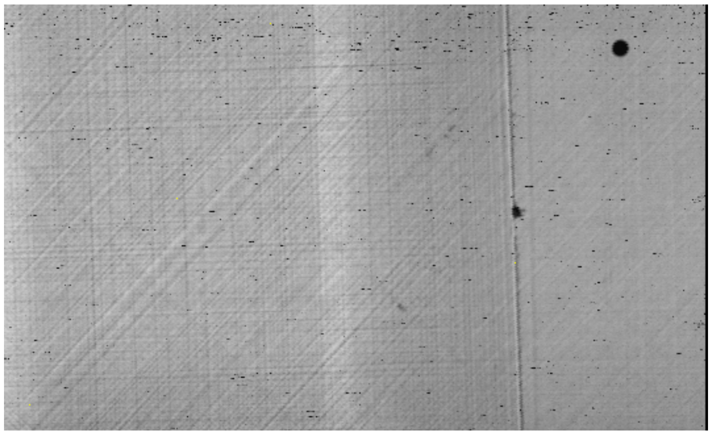
Adhesive Application



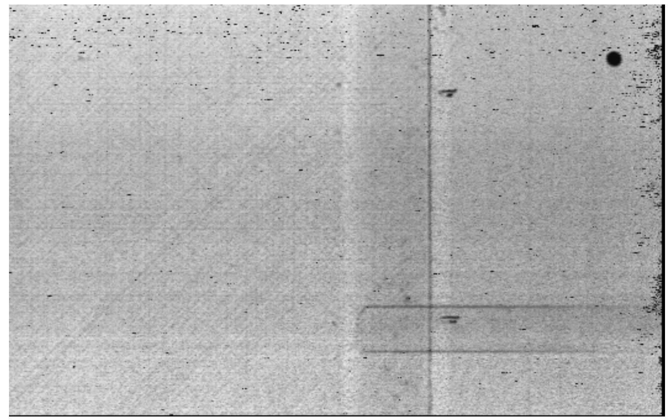
Repair Lay-up/ Thermocouple Installation

Repair Bagging

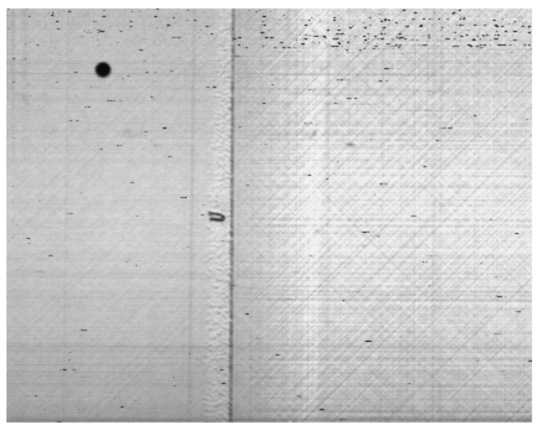
TTU Non-Destructive Inspection



Jet Fuel Contaminated Panel



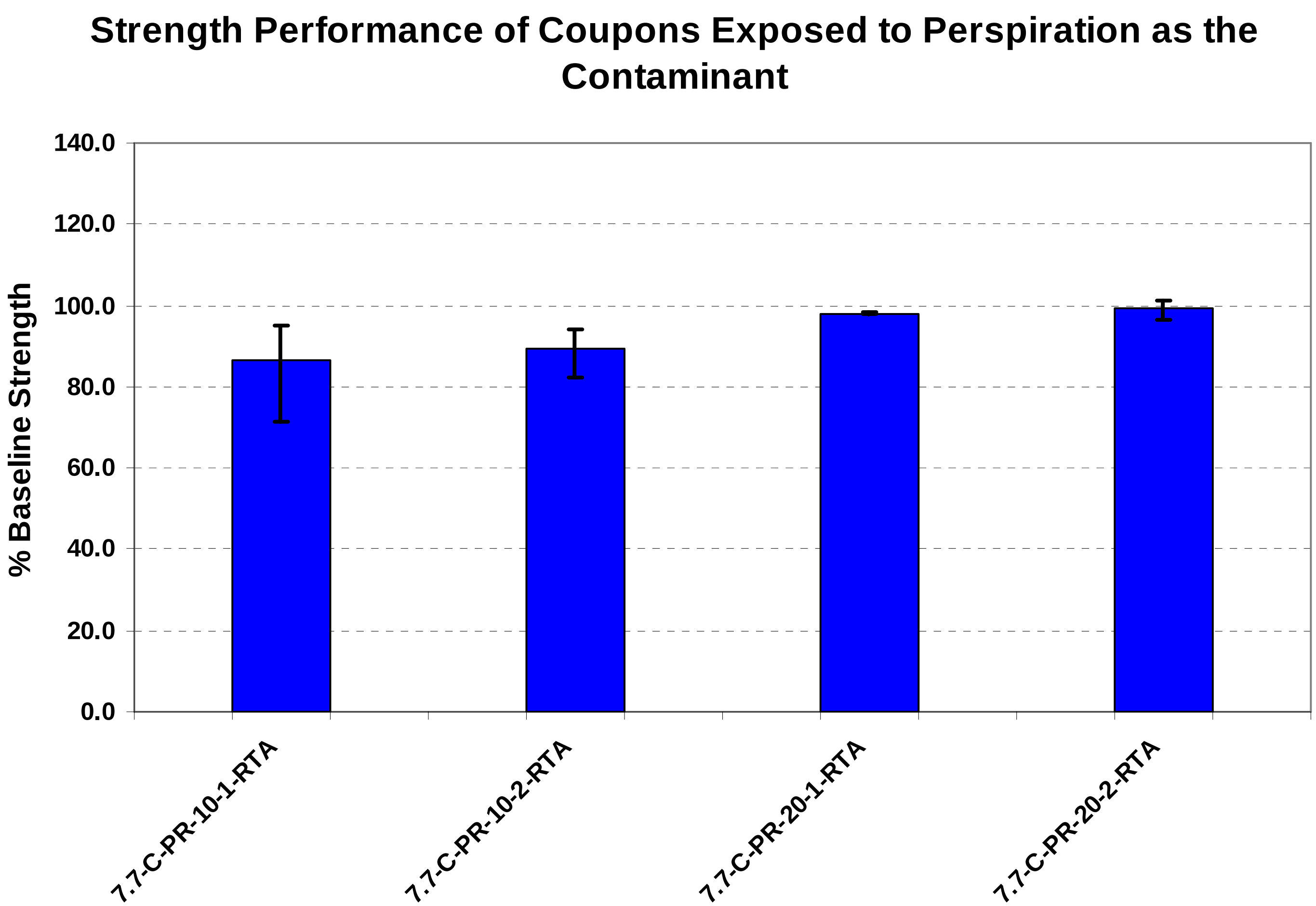
Skydrol Contaminated Panel



Water Contaminated Panel

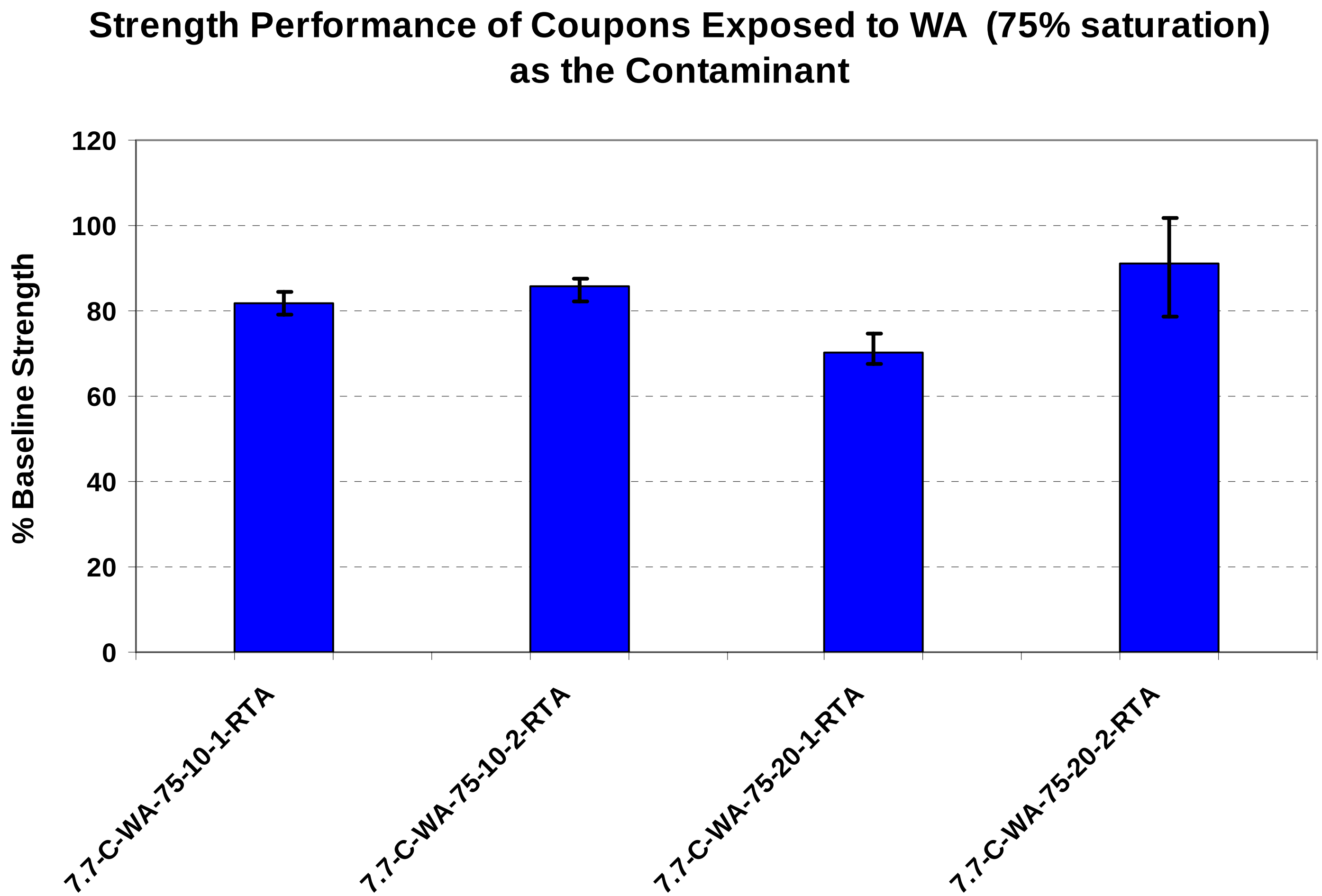
Contamination Results

Max Strength degradation 14%



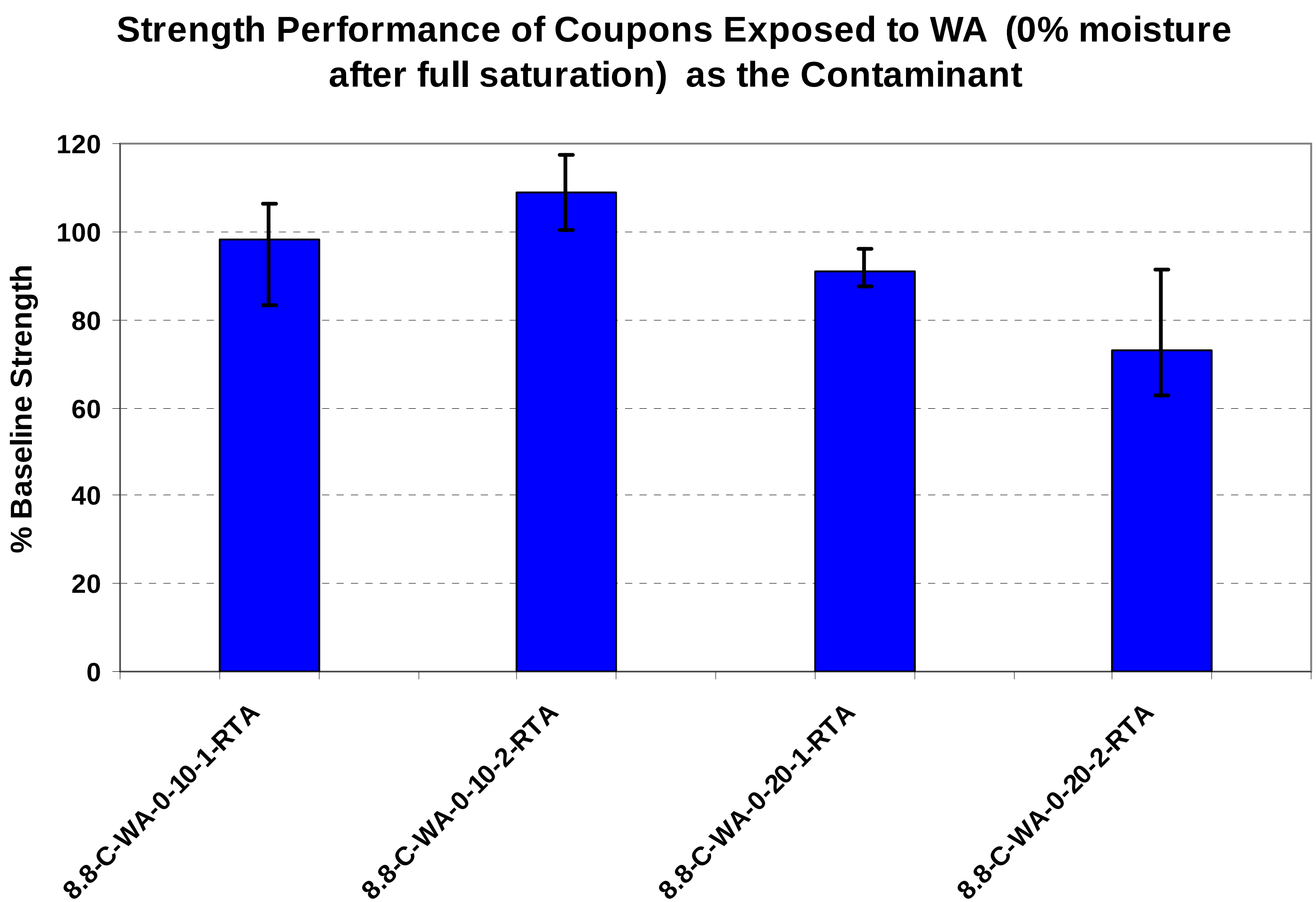
Contamination Results

Max Strength degradation 30 %



Contamination Results

Max Strength degradation 27%



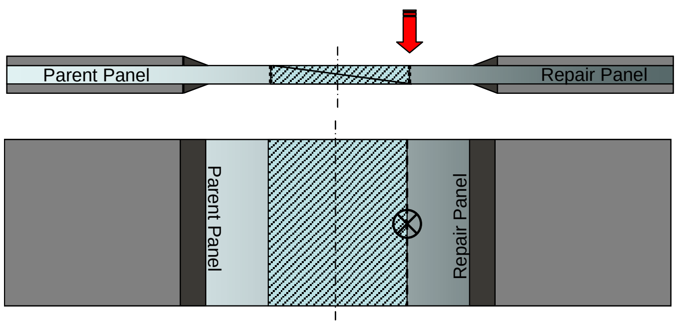
Methodology
Effects of Contamination

- Static data showed a lower strength performance for all panels contaminated with PR, WA75%, WA 50%, WA 25%, WA 0%
- RTA Static data showed minor strength degradation for panels contaminated with JF, SH and PS
- Need fatigue data to confirm results

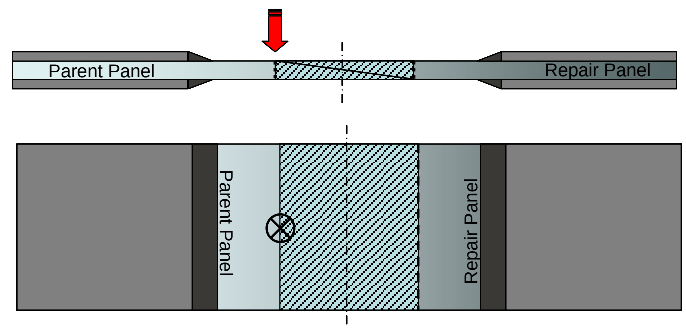
Methodology – Damage Effects

- 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.

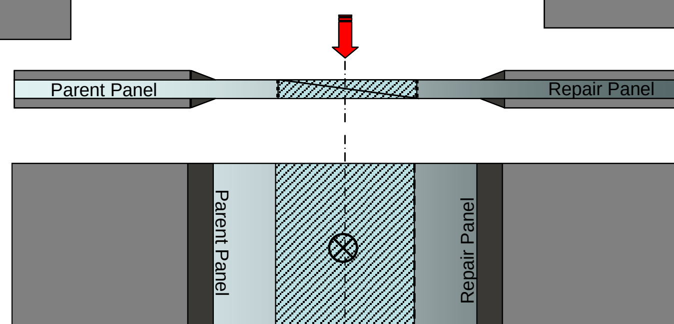
Tip of the scarf far side TF



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

18 ply configurations

Impact Energy Level 200 in-lbs

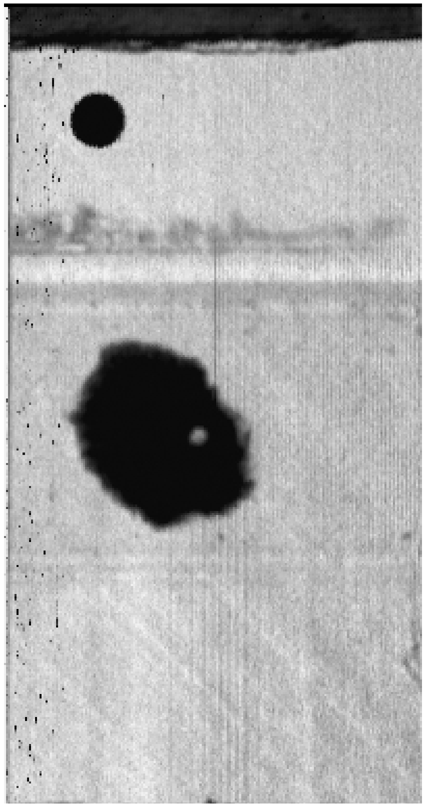
Depth: 0.01”

48 ply configurations

Impact Energy Level 400 in-lbs

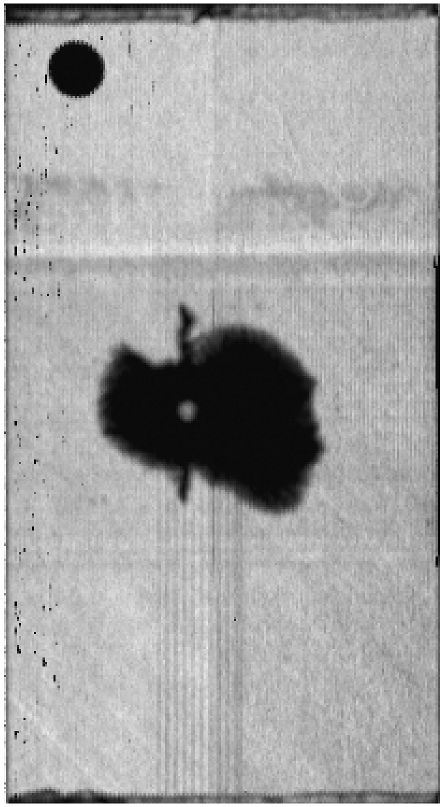
Depth: 0.01”

Methodology – Damage Effects



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

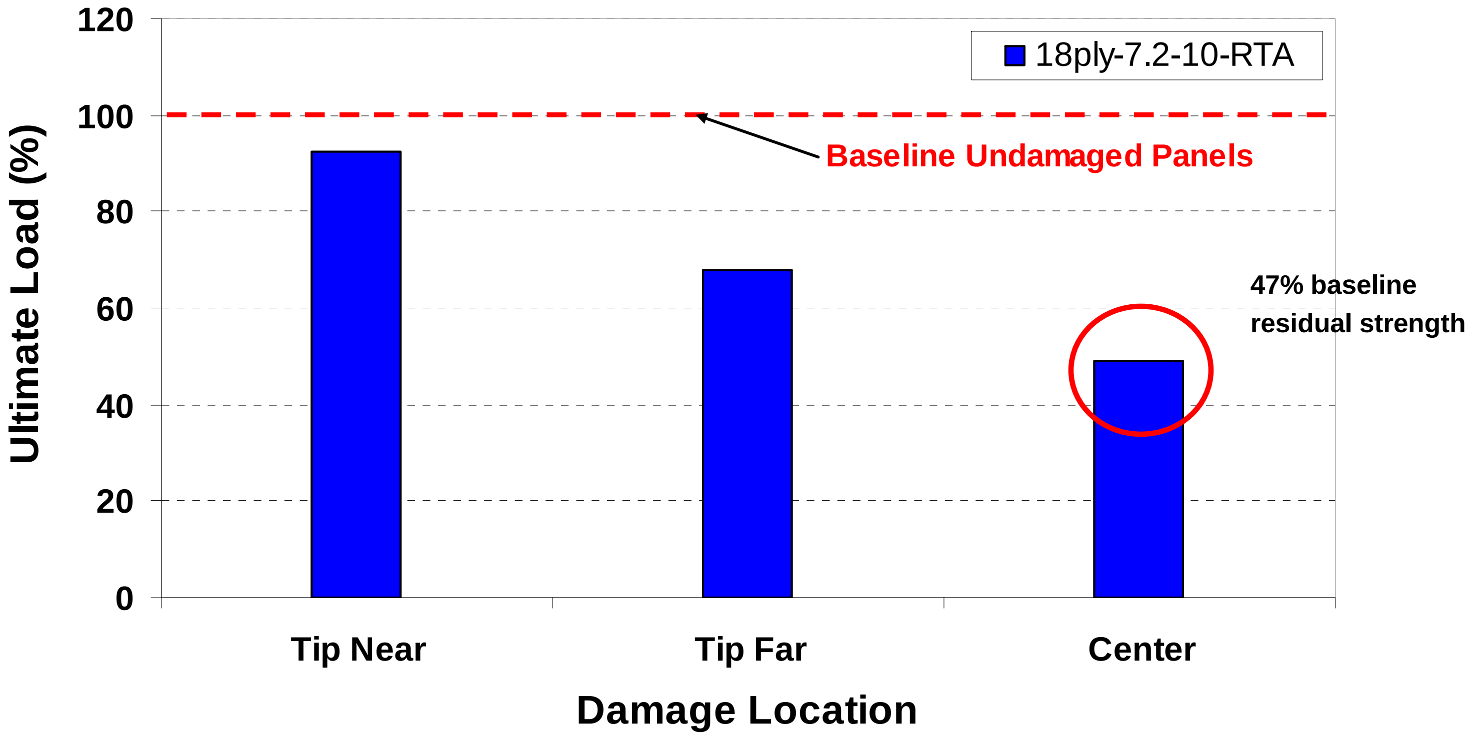
10941-18-7.2-20-CN-180W-2



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

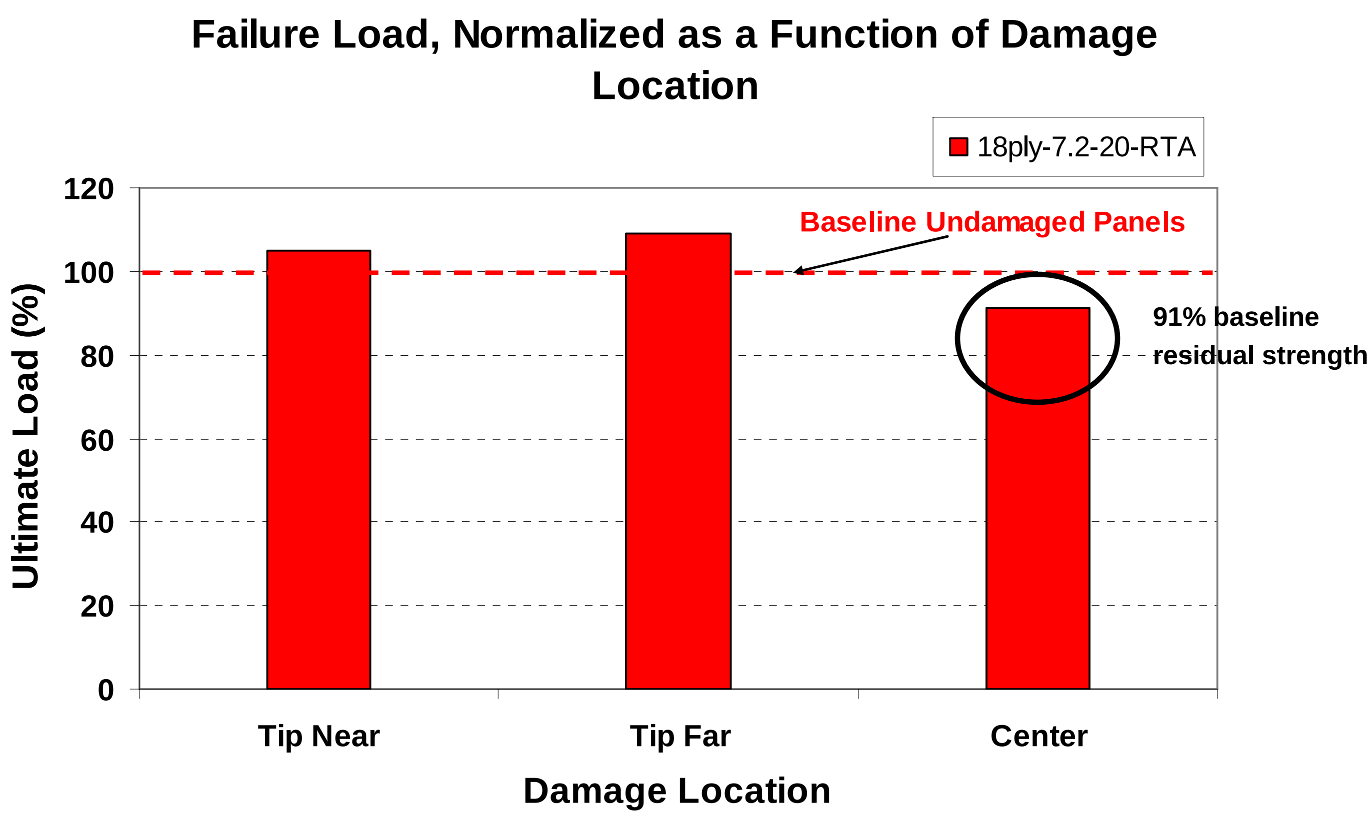
Methodology – Damage Effects Results

Failure Load, Normalized, as a Function of Damage Location



Methodology – Damage Effects Results

Max Strength Degradation 9 %



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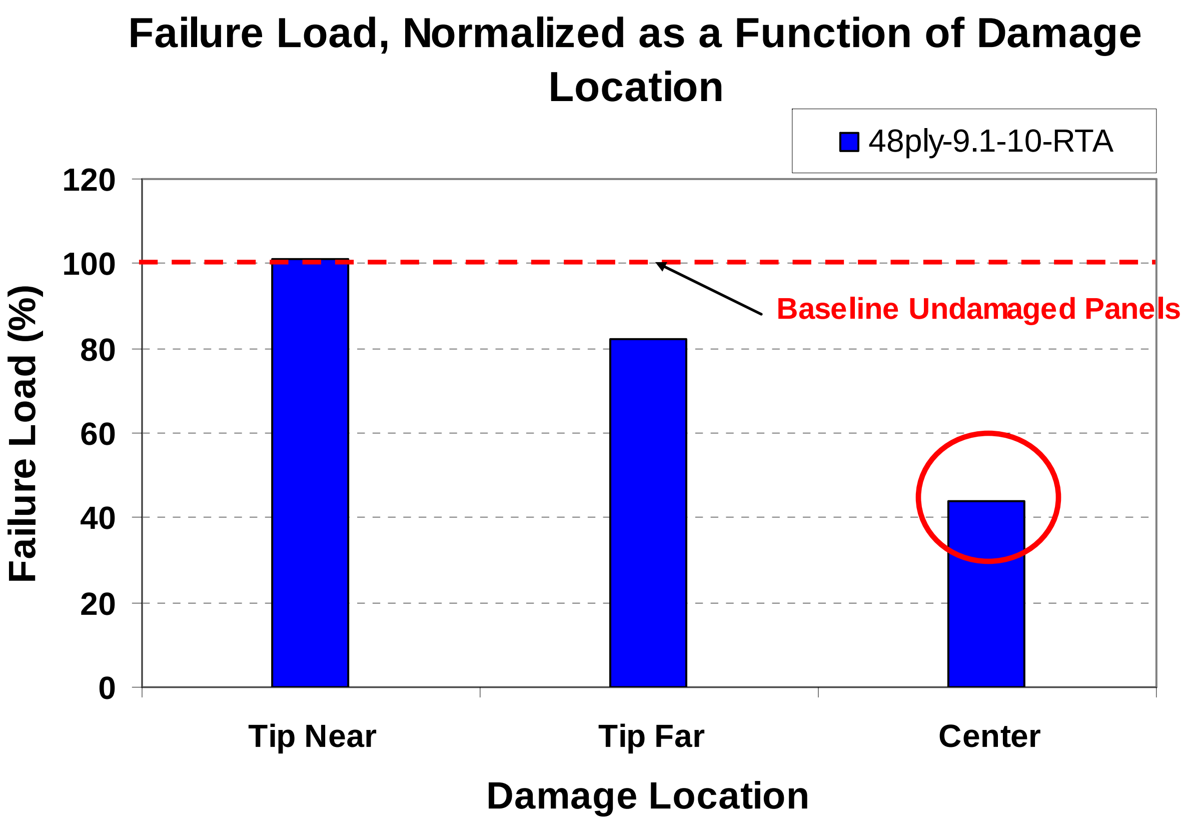
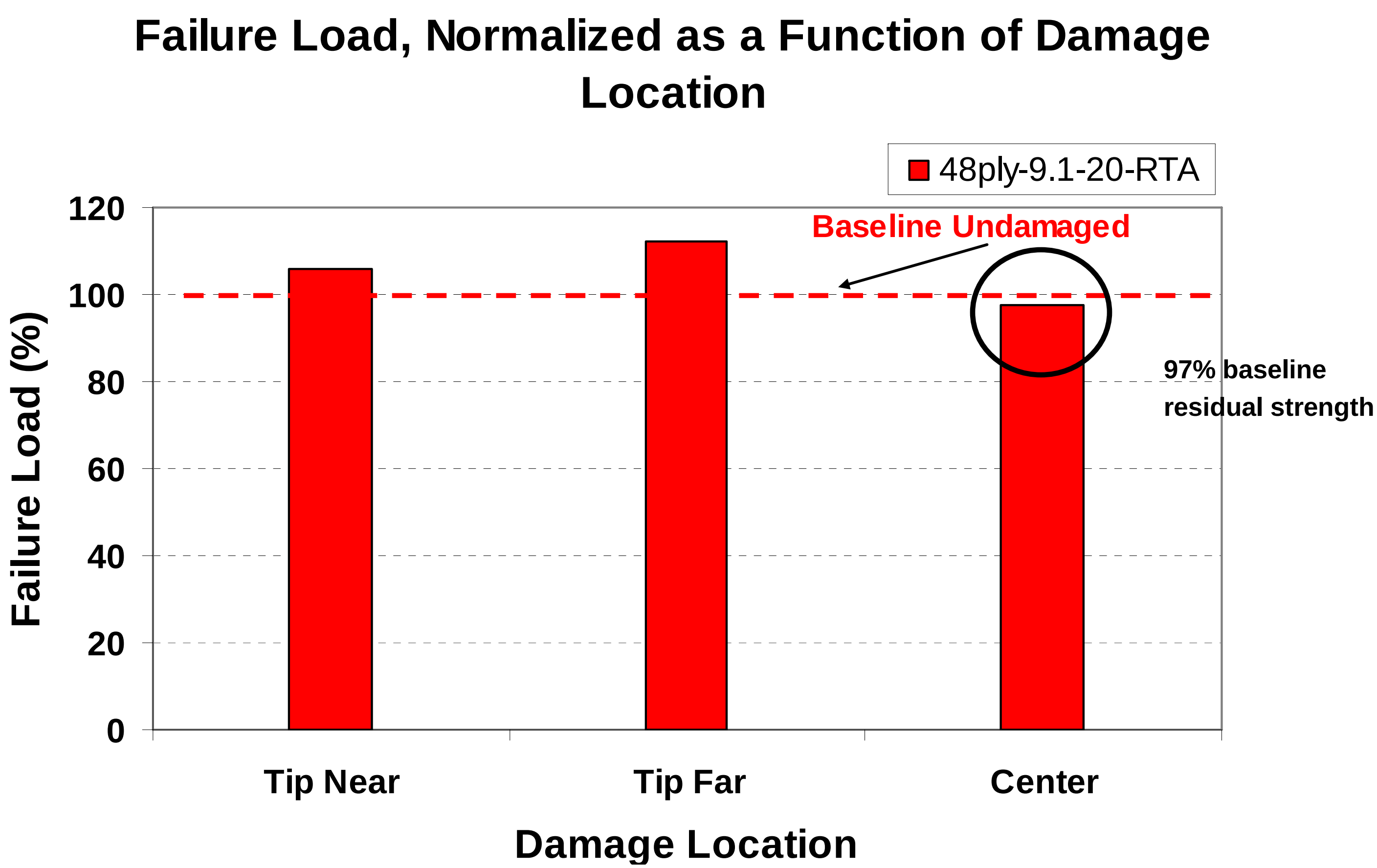
Methodology – Damage Effects Results



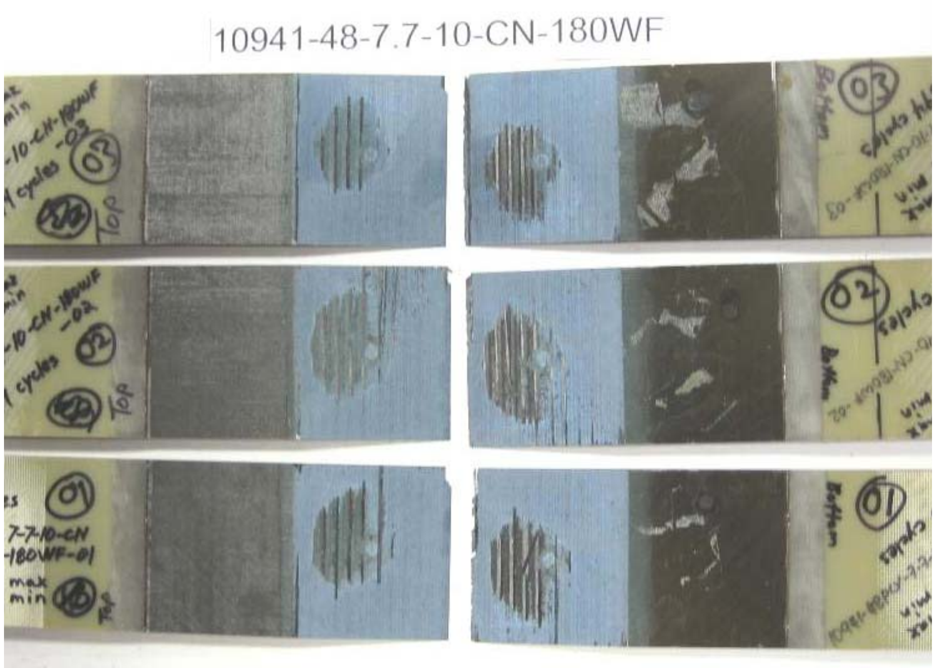
44% baseline residual strength

Methodology – Damage Effects Results

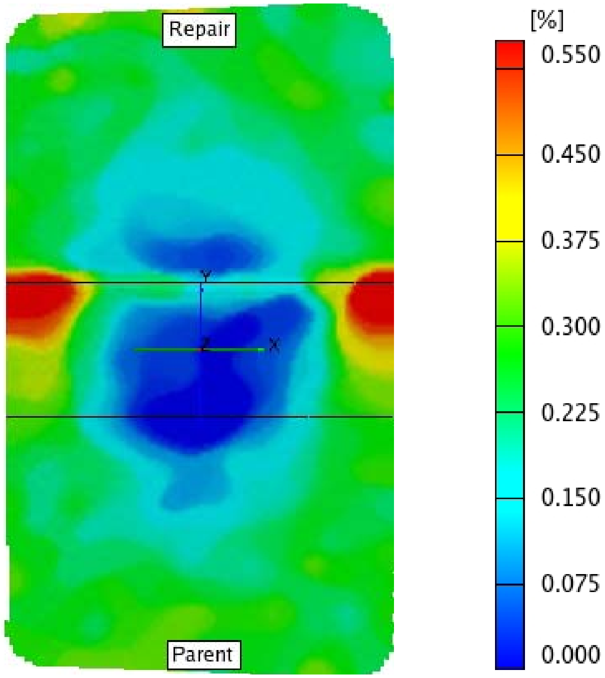
Max Strength Degradation 3%



Methodology – Damage Effects Results



Failure Modes (Mainly cohesive)



18-9.1-10-CN-RTA-01 ARAMIS strain Map

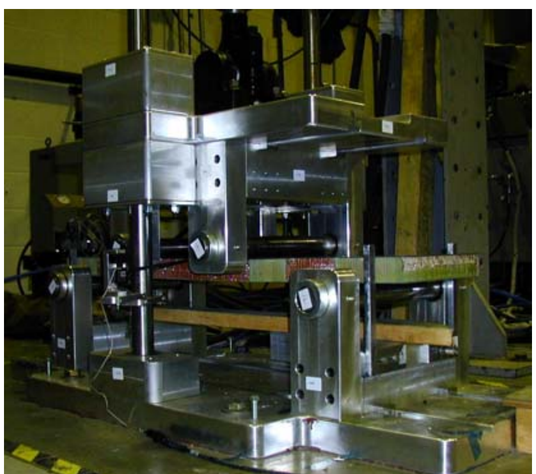
Methodology
Damage Effects Summary

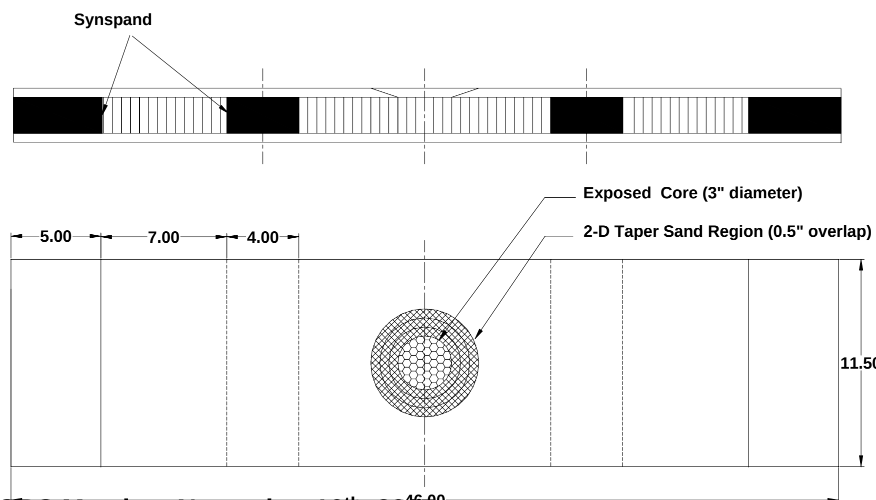
- Strength degradation is proportional to damage area
- Coupons impacted at the center of the repair, had the largest damage area and the lowest static strength
- The performance of coupons impacted at the edge of the repair was comparable to that of baseline repaired undamaged coupons
- The residual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

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.**

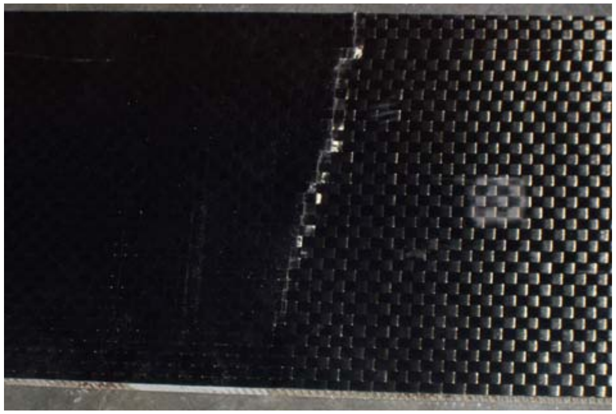
Repair Configuration	Core Cell Size	Repair Material	Repair Type	Scarf Overlap (in)	Static (RTA)	Fatigue (RTA)
2-D Compression Baseline	1/8	Toray T700/2510 PW Prepreg	Baseline Undamaged	NA	6	6
			Flush Scarf Repair	0.5	6	6
			External Patch	0.5	6	6
	1/8	CACRC Wet Lay-Up Repair	Flush Scarf Repair	0.5	6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





Methodology
Sandwich Repair Evaluation

➢ **To evaluate the strength and durability of OEM vs field repairs.**



Screening Panels yielded acceptable Failures (9000-10000 microstrain at failure)
Panel Manufacturing and scarfing complete
Repair in progress (OEM)

A Look Forward / 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