

Repair Development for a Composite Cryotank

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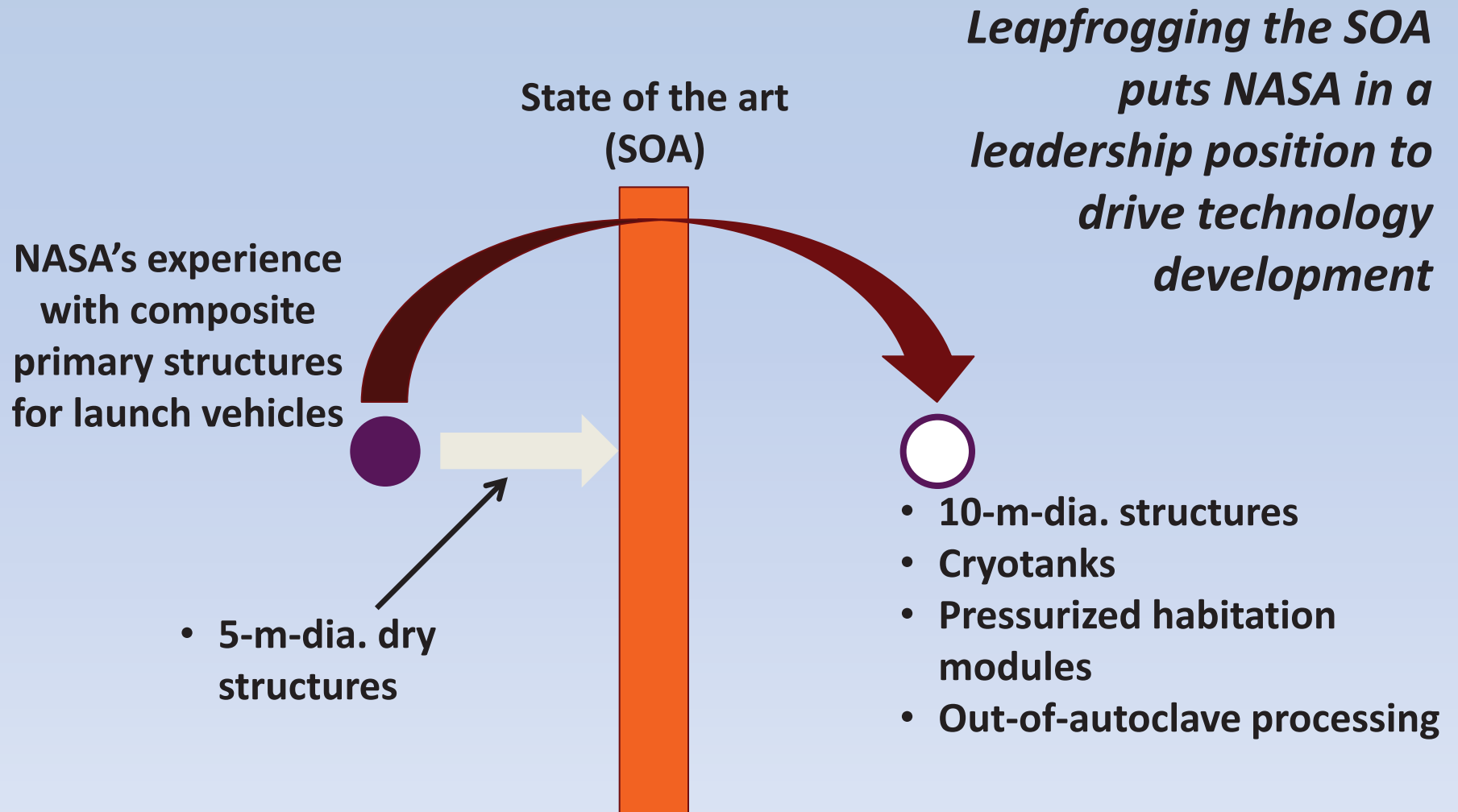
Brian J. Taylor

-
- Background of Composites and Composite Cryotank Project
 - Sandwich Panel Fabrication
 - Repair Development and Testing

What is a Composite?



- Basic Definition: A material made up of two or more different materials which keep their individual properties
- Advanced Composite Materials: A fiber reinforced matrix
- Matrix
 - Polymer/Epoxy
 - Metal
 - Ceramic
- Reinforcement
 - Glass
 - Aramid (Kevlar)
 - Carbon
 - Ceramic
 - Natural





Composite Cryotank Technologies and Demonstration

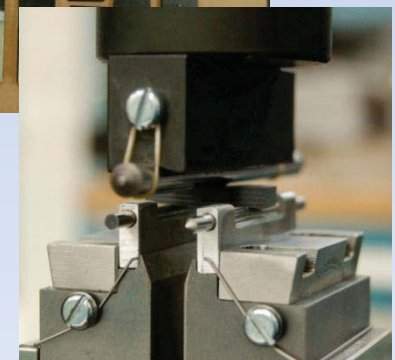


- Multi-center team responsible for developing and demonstrating advanced composite technologies
- Overall goal of the project is to achieve 30% weight savings 25% cost savings of LH₂ composite cryotanks
- KSC Objectives
 - Understand the properties of the composites
 - Perform hands on repair work at KSC
 - Develop out of autoclave repair cure process

- Void Analysis
 - Microscopy
 - Combustion
 - Compared with Acid Digestion at Glenn
- Mechanical Testing
 - Tensile
 - 16 ply specimens, all in the same direction
 - Short Beam Shear
 - 32 ply specimens, all in the same direction

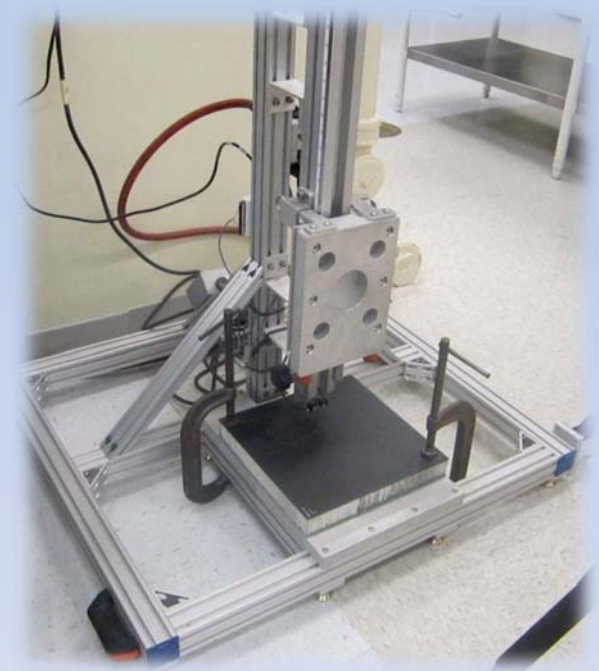


32-ply quasi isotropic panel, 100X



Repair Test Plan

1. Fabricate sandwich panel
2. Impact with 5.5 ft-lbs force (per ASTM 7136)
3. Remove damaged area
4. Scarf around damaged area
5. Repair with a honeycomb core plug and a patch
6. Edgewise compression test on control and repaired panels



Face Sheets

- HR40/5320-1 Unitape Prepreg
- 8-ply quasi-layup

Core

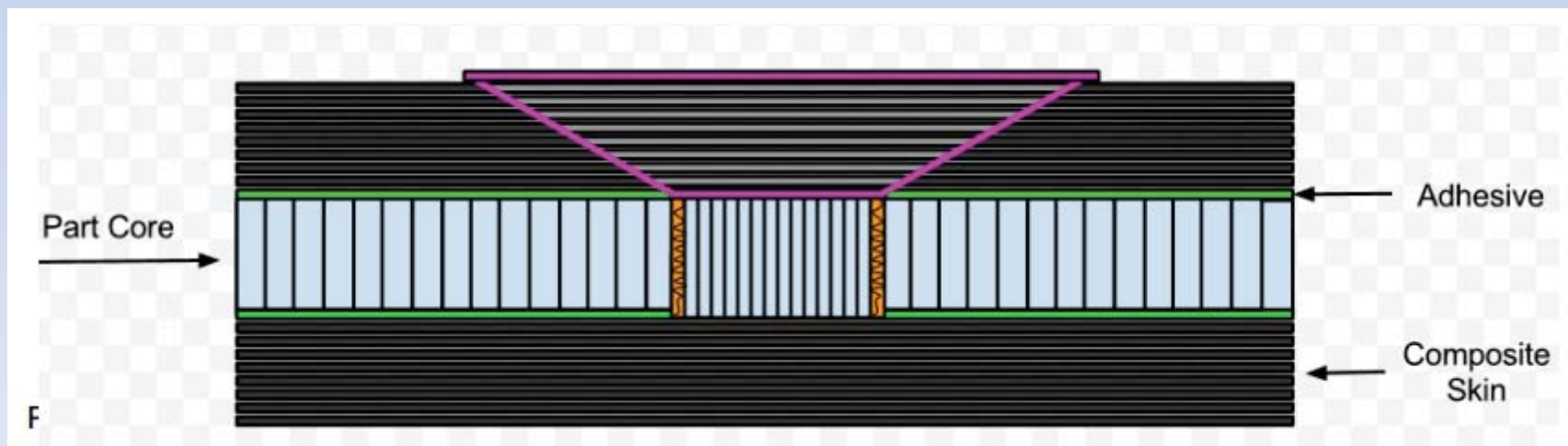
- 1.5" Aluminum Honeycomb
- FM-300 Film Adhesive

Repair Patch

- HR40/5320-1 Unitape Prepreg
- FM-300 Film Adhesive

Core Plug

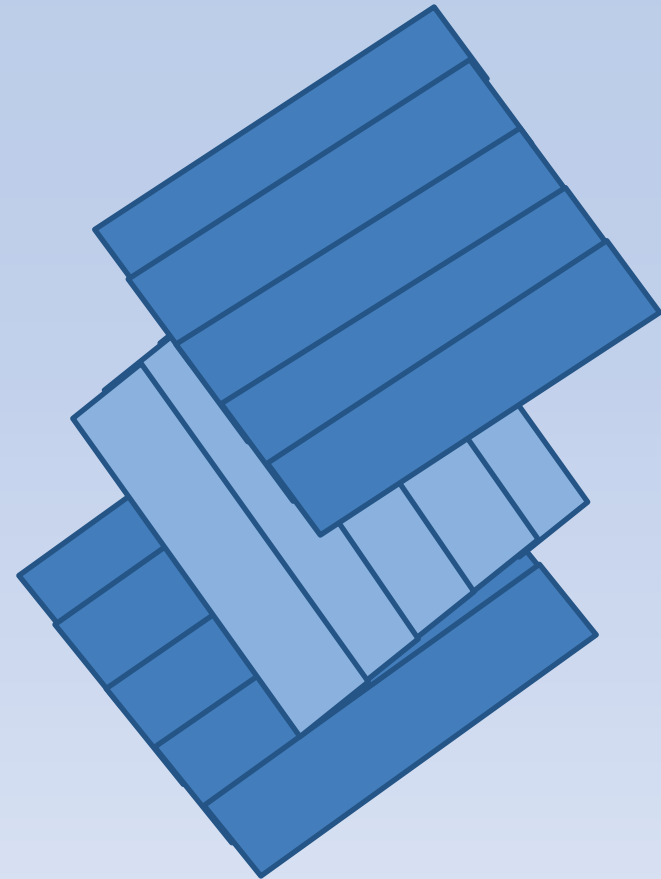
- 1.5" Aluminum Honeycomb
- Hysol MA 562 Foaming Adhesive
- FM-300 Film Adhesive

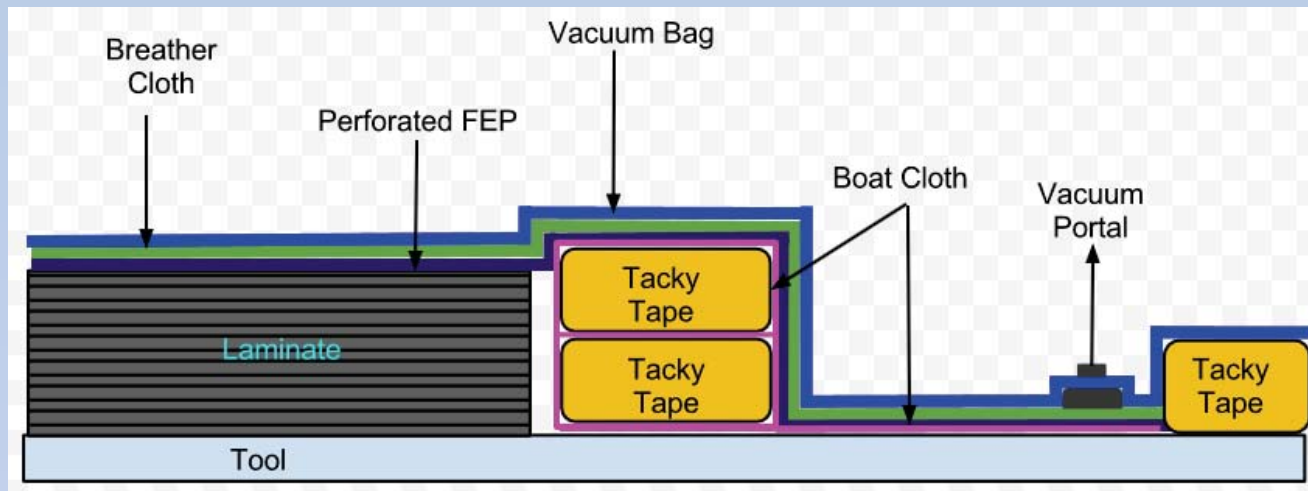


- HR40/5320-1 Prepreg Unitape
 - Fibers preimpregnated with resin
 - Hand Layup onto flat tool
 - Out of Autoclave curing

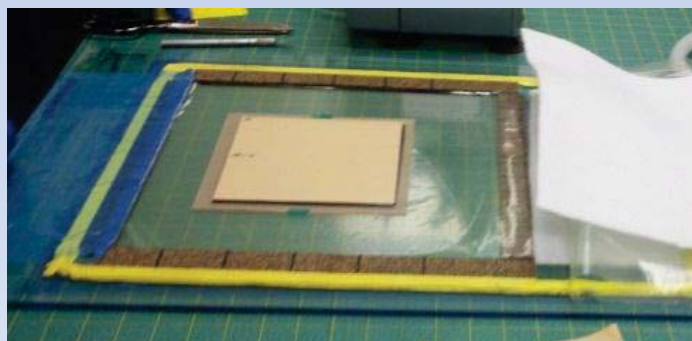


[0,90] Composite Microscopy Image





The Panels Are Made by Hand Lay-up Method



Prepreg Sheets Hand Lay-up



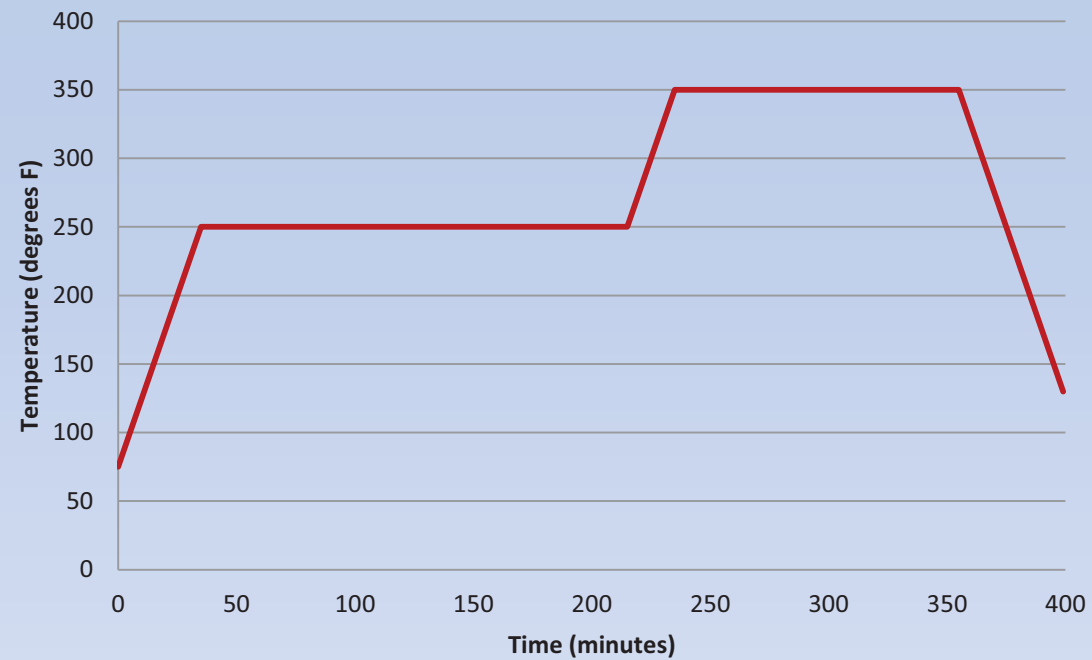
Vacuum Debulk of Composite Panel

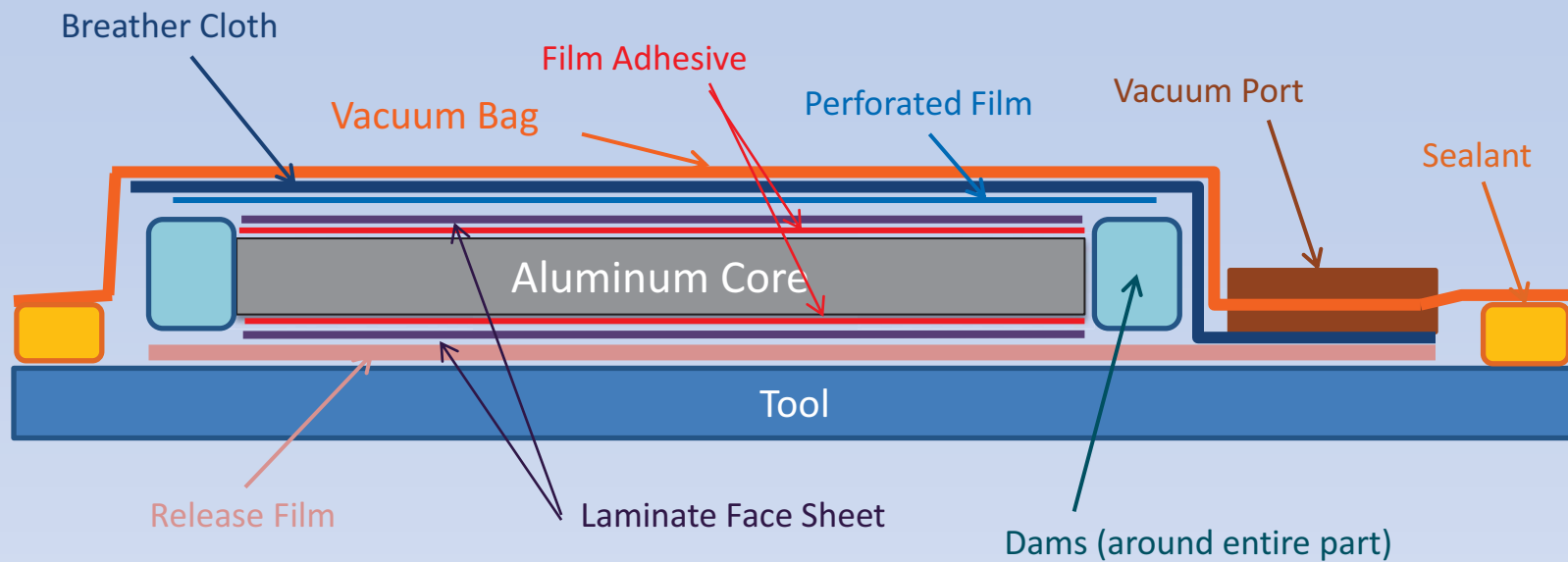


Oven Cure of Panel Under Vacuum

5320-1 Cure Cycle

5320-1 Cure Cycle

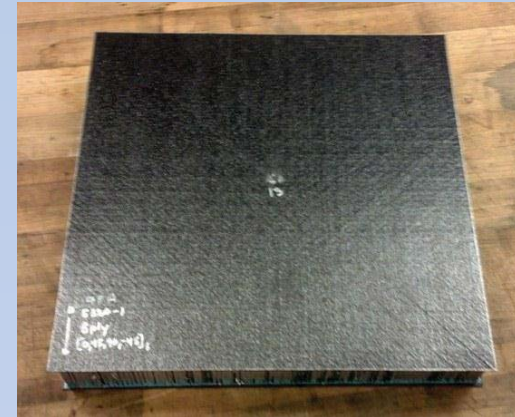




Sandwich Panels after Impact



Panel A



Panel C

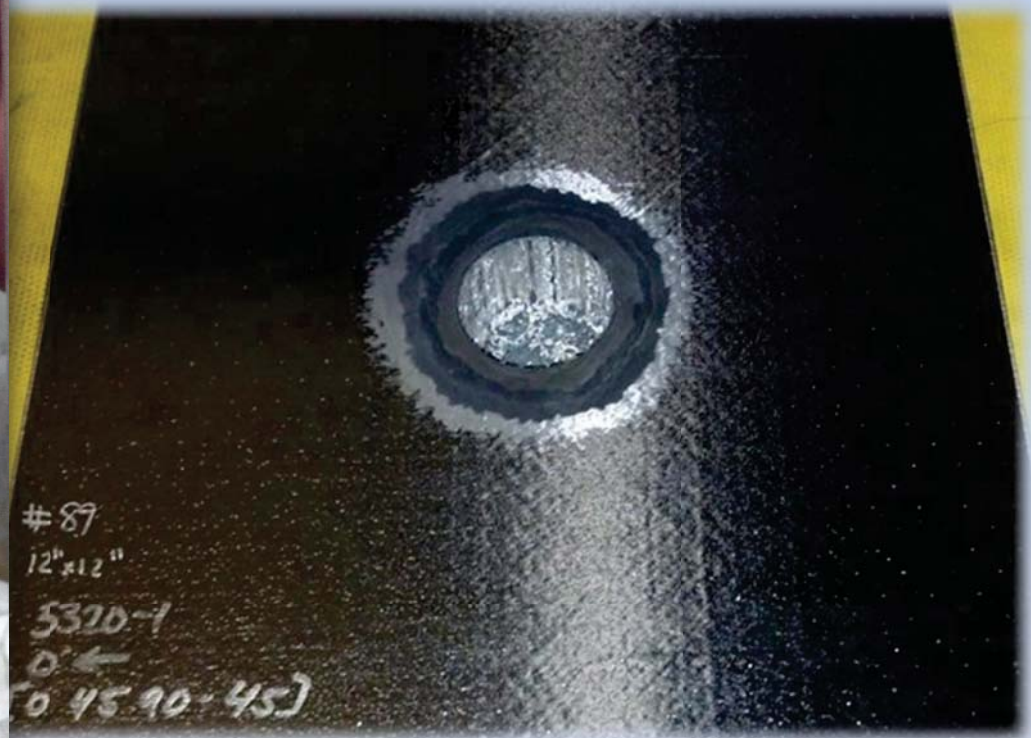


Panel B



Panel D

Sandwich Panel Scarfing



- Method I: Pre-cured Patch
 - Patch was cured in an oven with the standard cure cycle
 - Patch was bonded to the part at 350°F for 1 hour
- Method II: Co-cured Patch
 - Patch was cured on the part with a hot bonder
 - Used cure cycle of the material: 250°F for 3 hours and 350°F for 2 hours
- Method III: Partially Cured Patch
 - Developed a method to determine the cure cycle based on research of previous work. Determined the best cure cycle from study to be:
 - Patch partially cured at 200°F in an oven for 1 hour
 - Patch fully cured at 350°F with the hot bonder for 2 hours on the part

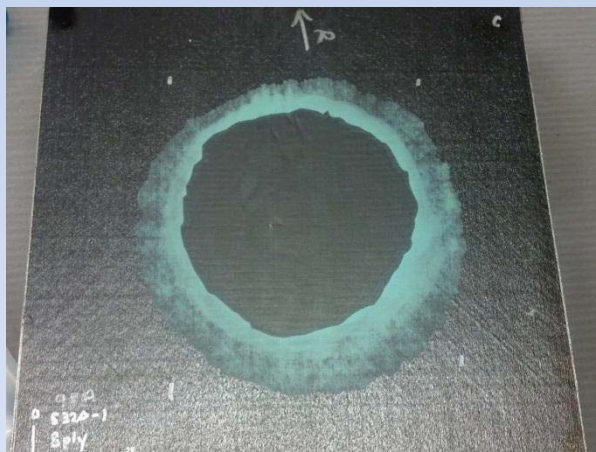
Repaired Panels



Panel A: Pre-cured Patch



Panel B: Pre-cured Patch



Panel C: Co-cured Patch



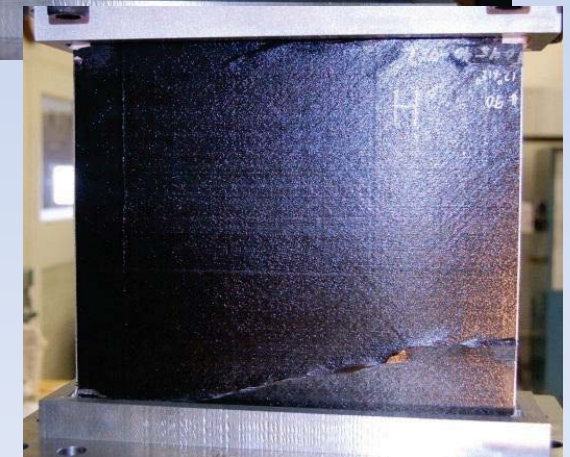
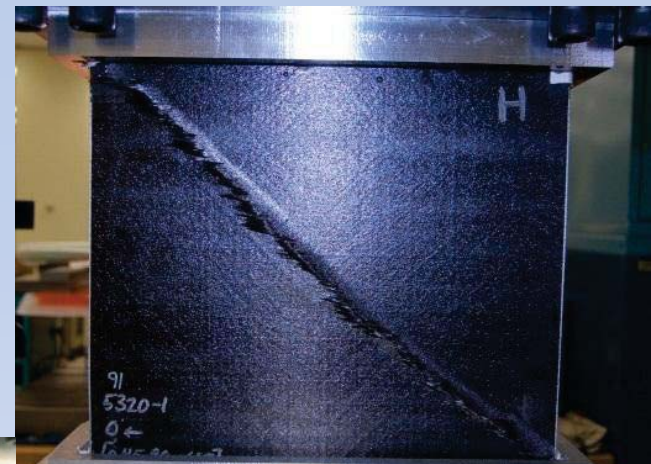
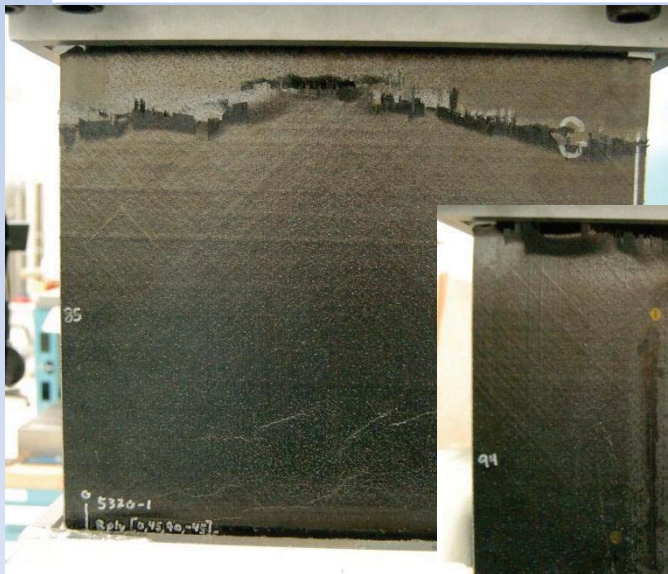
Panel D: Co-cured Patch

- ASTM C 364: Standard Test Method for Edgewise Compressive Strength of Sandwich Constructions
- Provides a load carrying capacity of the construction of the sandwich panels after a repair has been performed.
- Panels potted into end caps



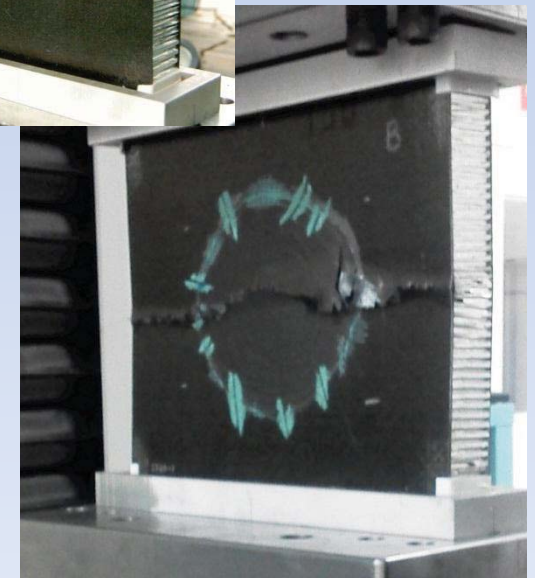
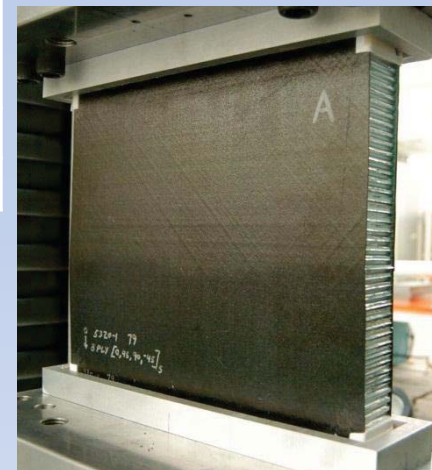
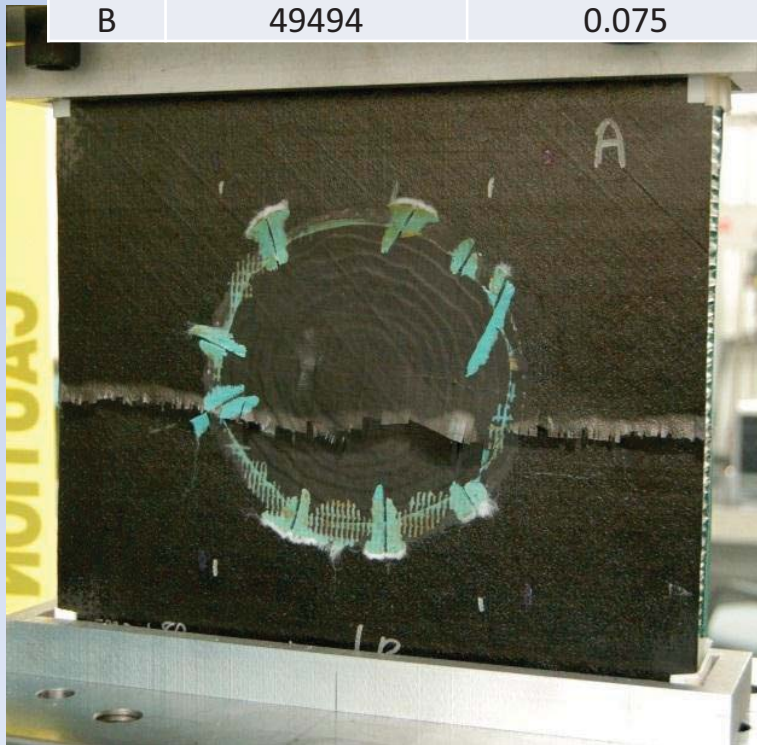
Control (no damage, no repair)

Panel ID	Maximum Compressive Load (lbf)	Compressive Extension at Max Load (in)	Compressive Stress at Max Load (ksi)
G	51775	0.082	52.4
H	Error During Data Collection		



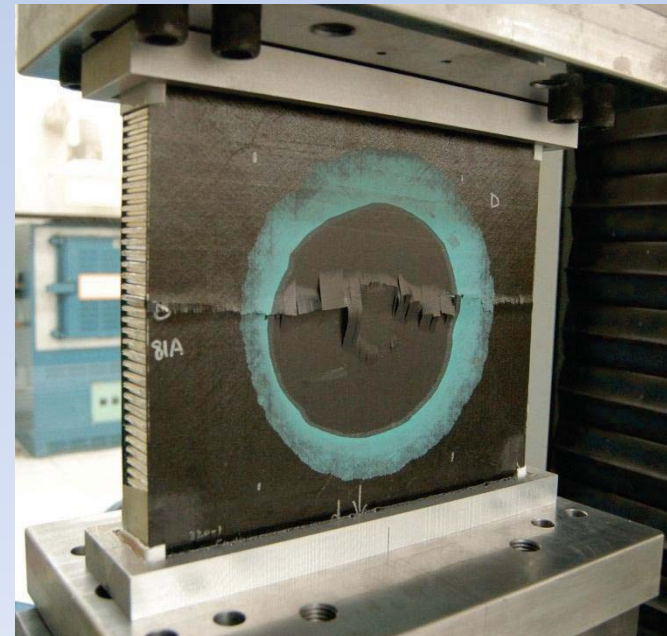
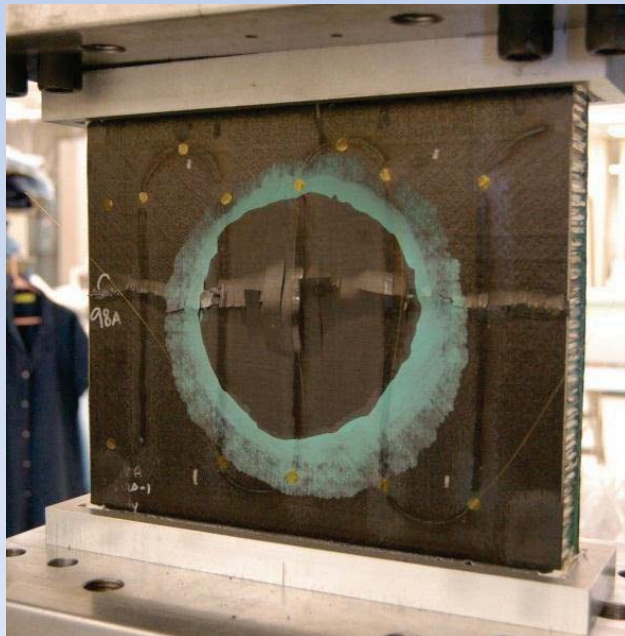
Pre-cured Patch

Panel ID	Maximum Compressive Load (lbf)	Compressive Extension at Max Load (in)	Compressive Stress at Max Load (ksi)
A	46608	0.071	47.4
B	49494	0.075	50.0



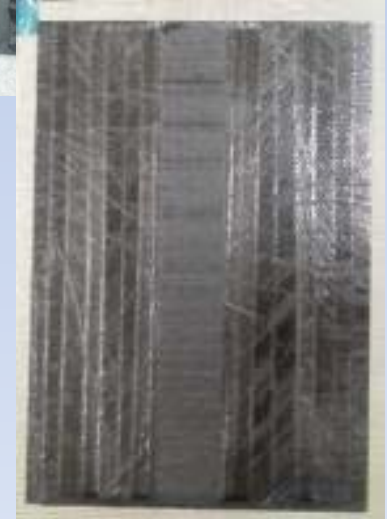
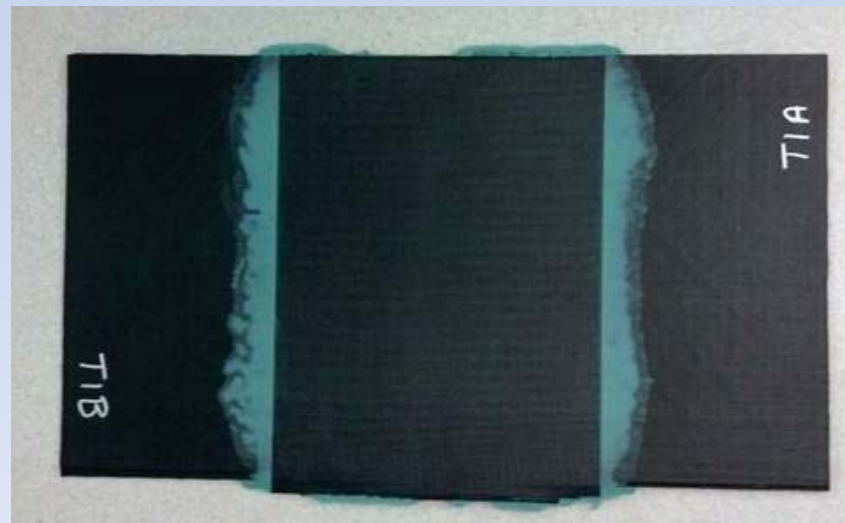
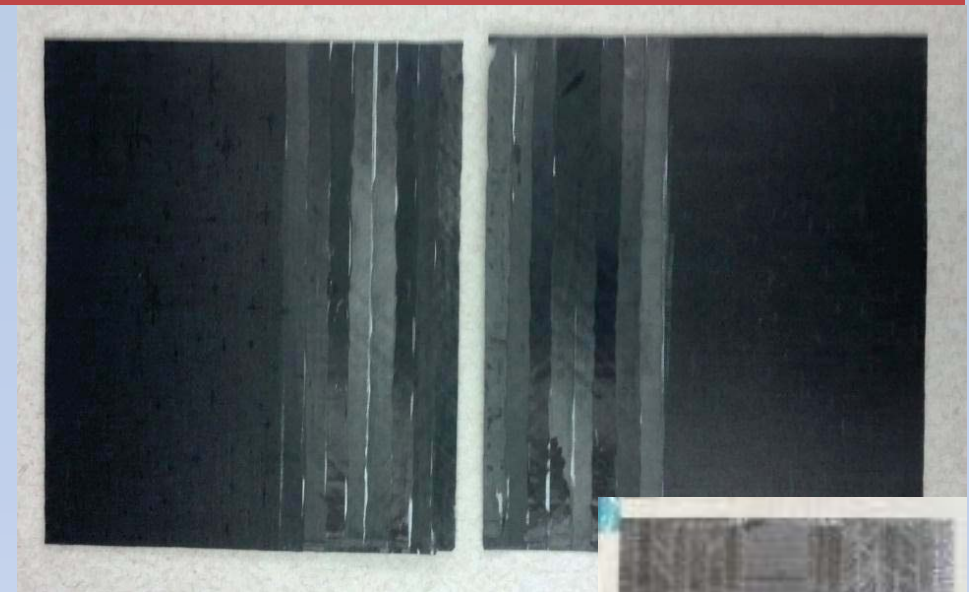
Co-cured Patch

Panel ID	Maximum Compressive Load (lbf)	Compressive Extension at Max Load (in)	Compressive Stress at Max Load (ksi)
C	38383	0.059	42.2
D	38992	0.059	39.3



- Partially curing the patch in the oven allows the patch to have some rigidity and hold its shape but still have some flexibility to fully conform to the part
- Beneficial for curves and complex shapes
- Decreases repair time by having commonly damaged area shapes, and patch sizes available
- Decreases the cure time on the vehicle

In order to determine the optimal degree of partial cure, laminate panels were repaired with patches which saw a range of cure conditions



- Patches cured in oven under vacuum at the temperature and time given
- All patches were de-bulked on the part for 30 minutes prior to hot bond cure
- Repairs cured on hot bonder at 250°F for time shown and then at 350°F for 2 hours

Sample ID	Cure in Oven		Hot Bonder Cure Time at 250F (min)
	Temp (deg F)	Time (min)	
1-AB	150	15	165
1-CD	150	30	150
2-AB	150	60	120
2-CD	200	15	165
3-AB	200	30	150
3-CD	200	60	120
4-AB	250	15	165
4-CD	250	30	150
5-AB	250	60	120

- Test panels were cut into 1" strips and tested as a comparative study

Sample ID	Cure in Oven		Hot Bonder Cure Time at 250F (min)	Observations After Oven Cure	Average Tensile Strength (psi)
	Temp (deg F)	Time (min)			
1-AB	150	15	165	Patch was still tacky, pliable	38107
1-CD	150	30	150	Patch was still tacky and pliable	38689
2-AB	150	60	120	Patch was not very tacky or pliable	43624
2-CD	200	15	165	Not very tacky or pliable	32660
3-AB	200	30	150	Patch was not very tacky or pliable	39209
3-CD	200	60	120	Patch was not very tacky or pliable	54811
4-AB	250	15	165	Very Stiff	31728
4-CD	250	30	150	Very Stiff, like it was fully cured	49254
5-AB	250	60	120	Very stiff	42049

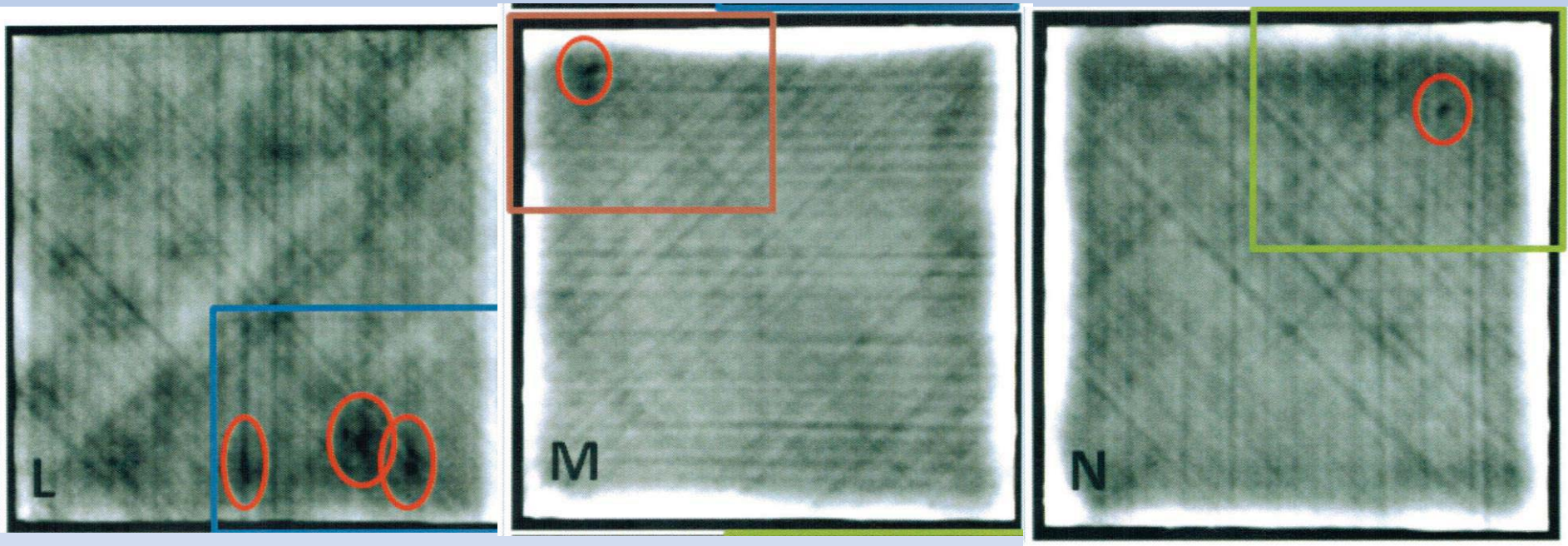




Phase II: NDE during Repair Process



- Three additional sandwich panels were fabricated with the same materials
- The panels received IR Thermography scans after each event:
 - Fabrication
 - Impact (to 5 ft-lbs)
 - Repair
- Three patch methods: pre-cured, co-cured, and partially cured patches used on the panels

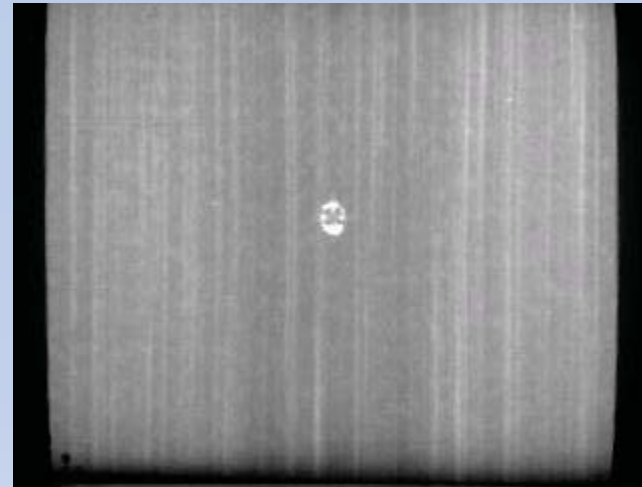


Planned for Co-cured patch

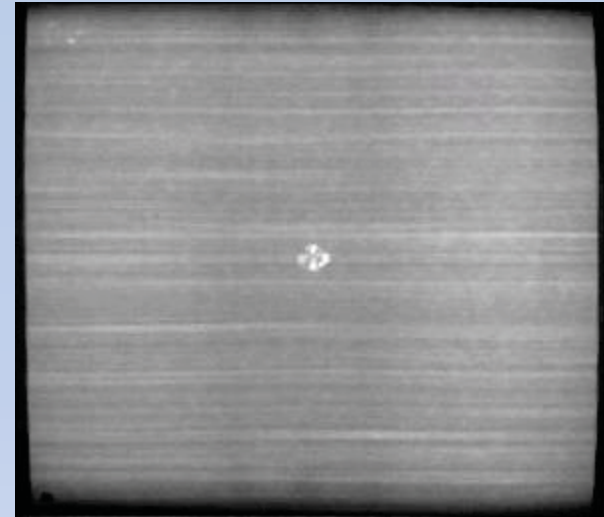
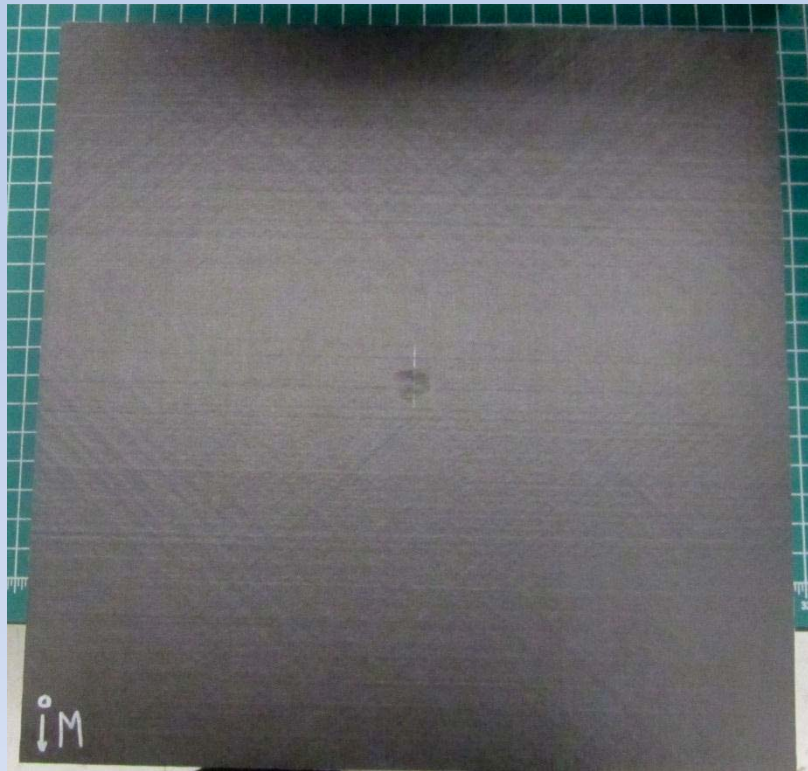
Planned for partially cured patch

Planned for pre-cured patch

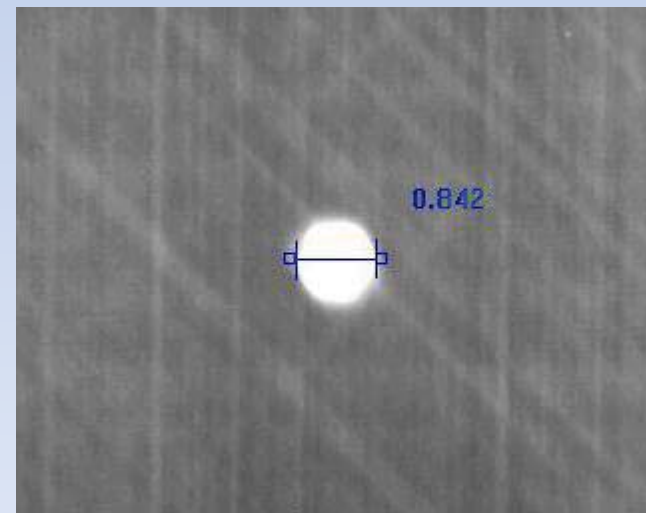
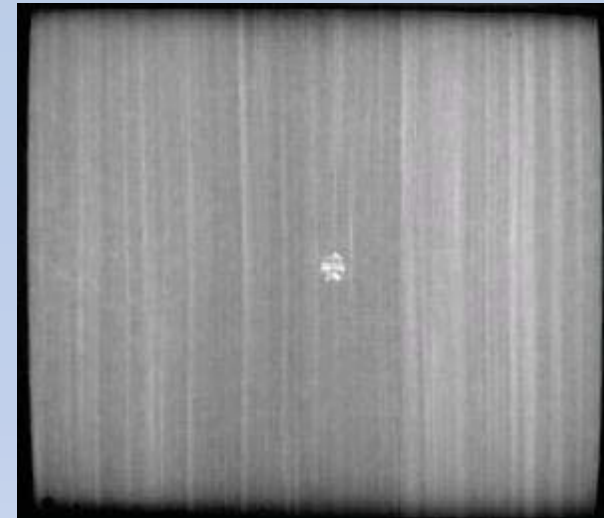
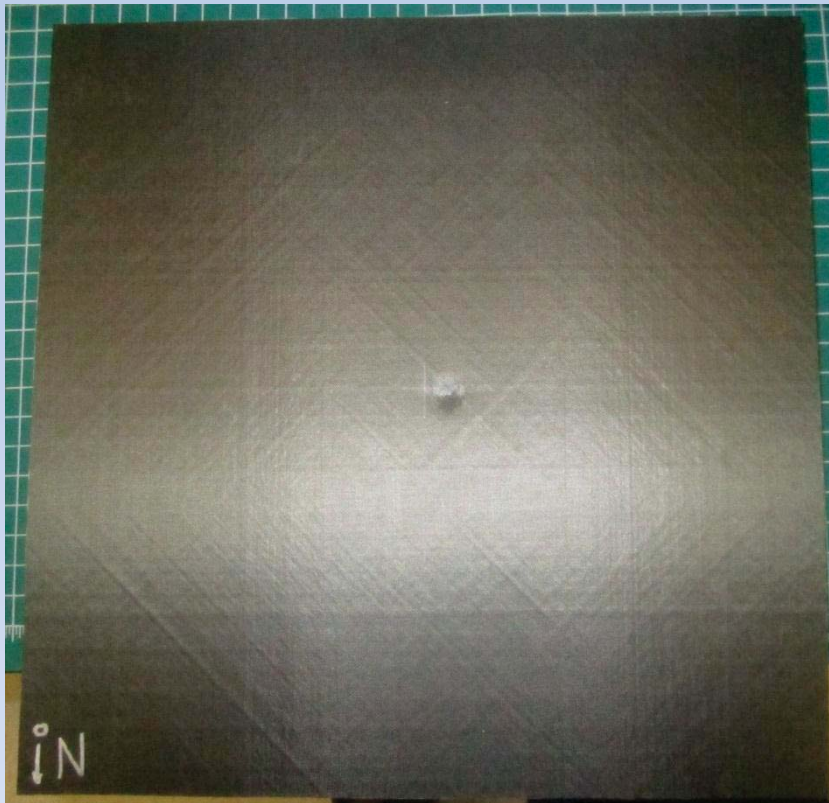
After Impact



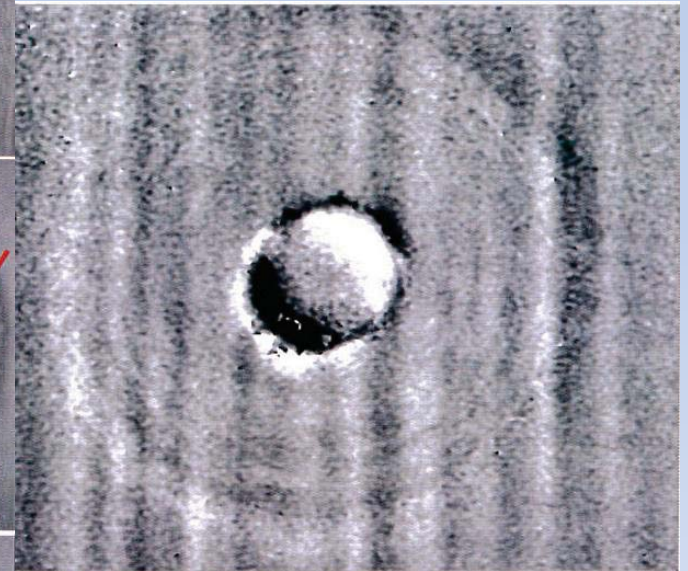
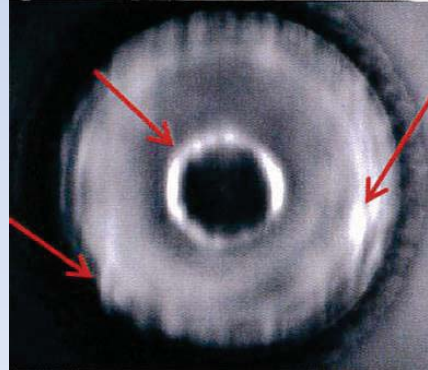
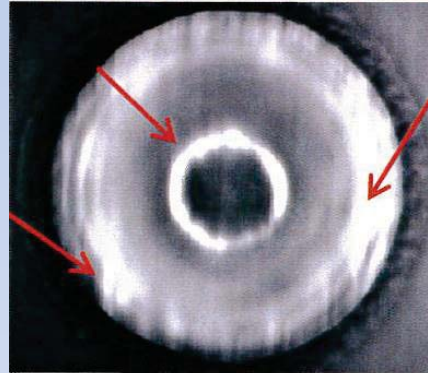
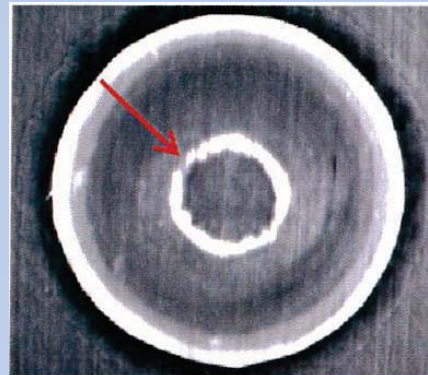
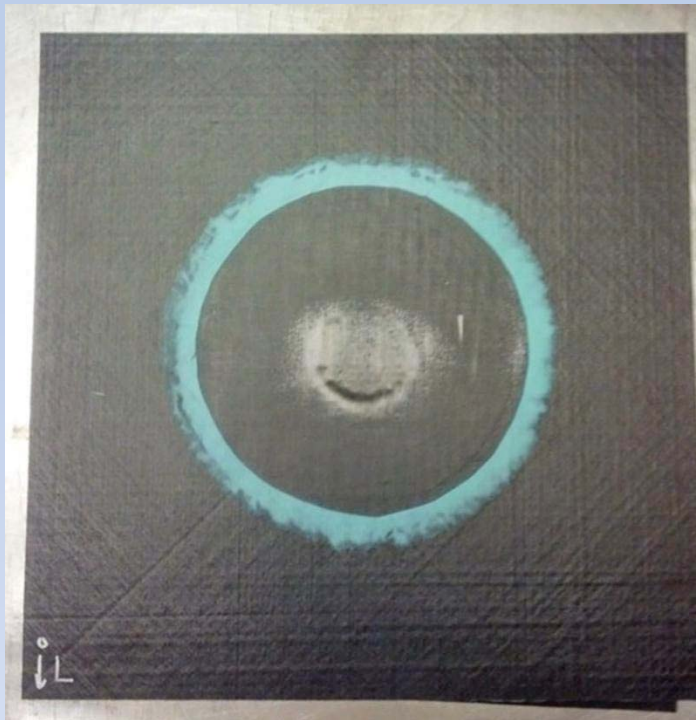
After Impact



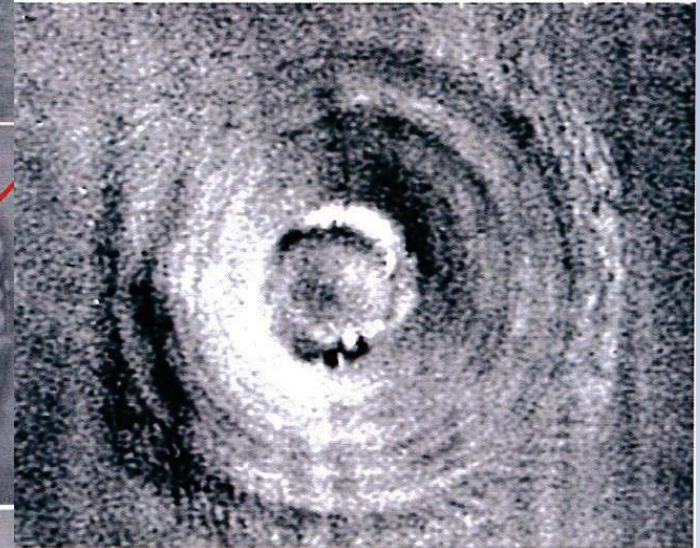
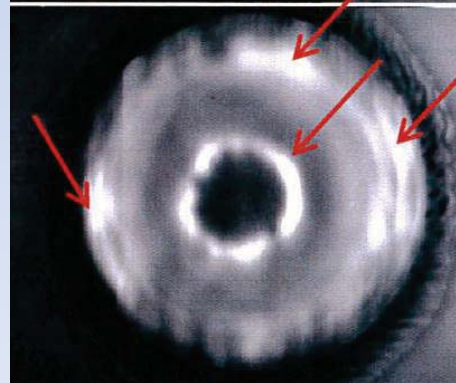
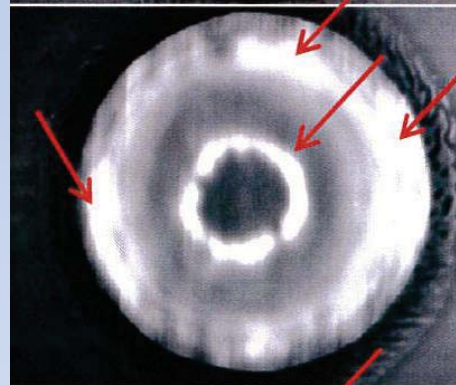
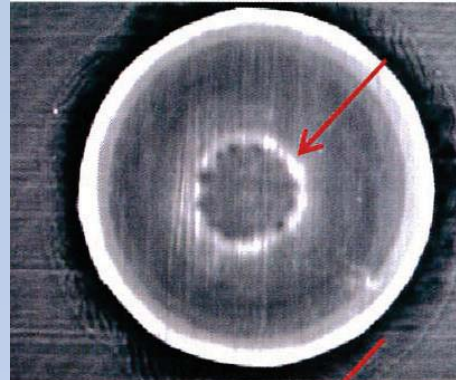
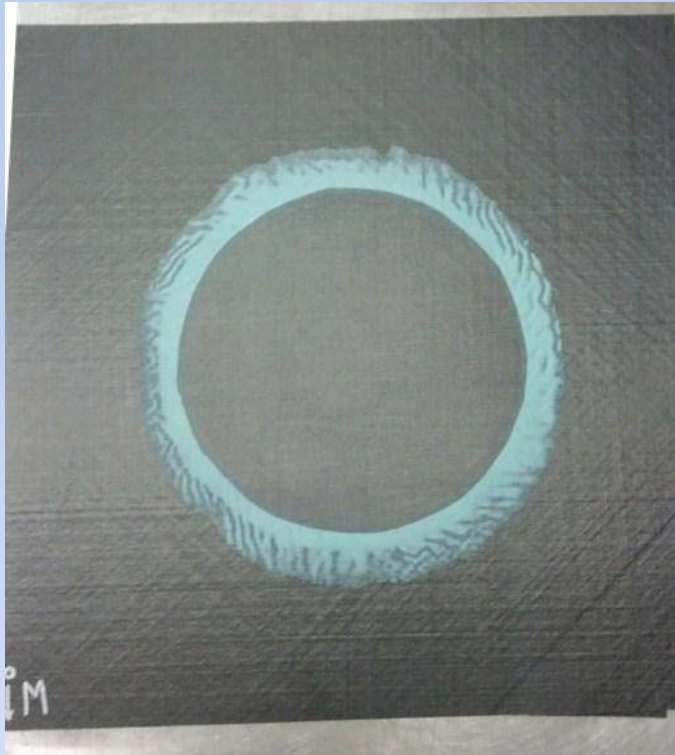
After Impact



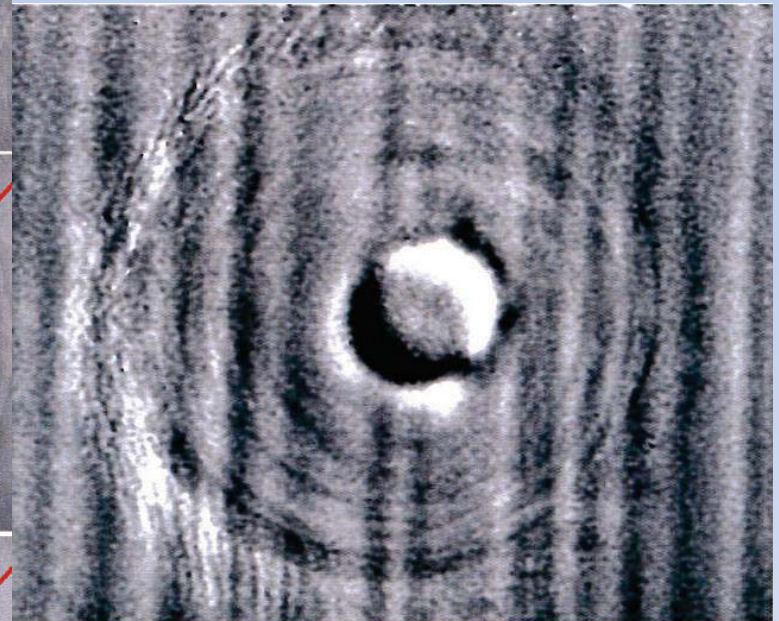
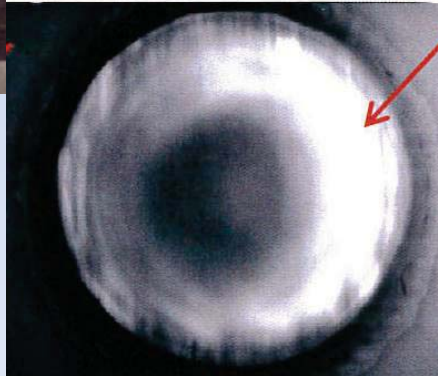
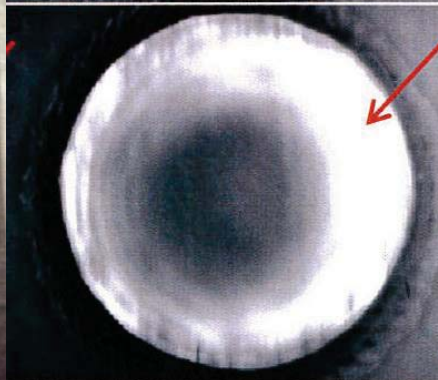
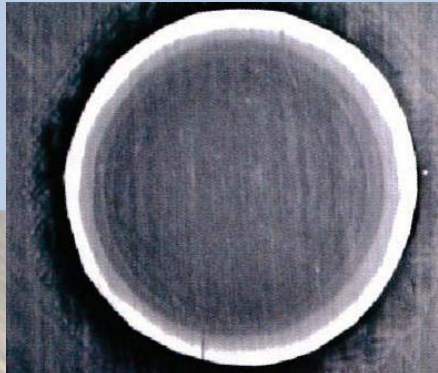
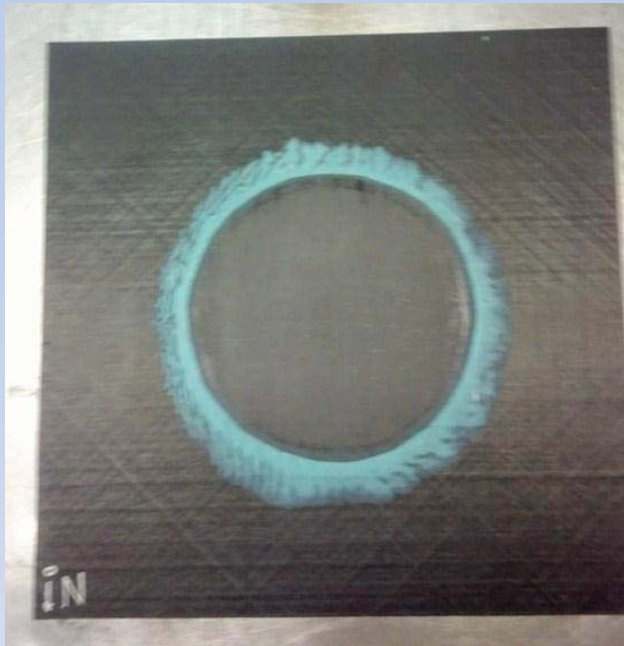
After Repair – Co-cured Patch



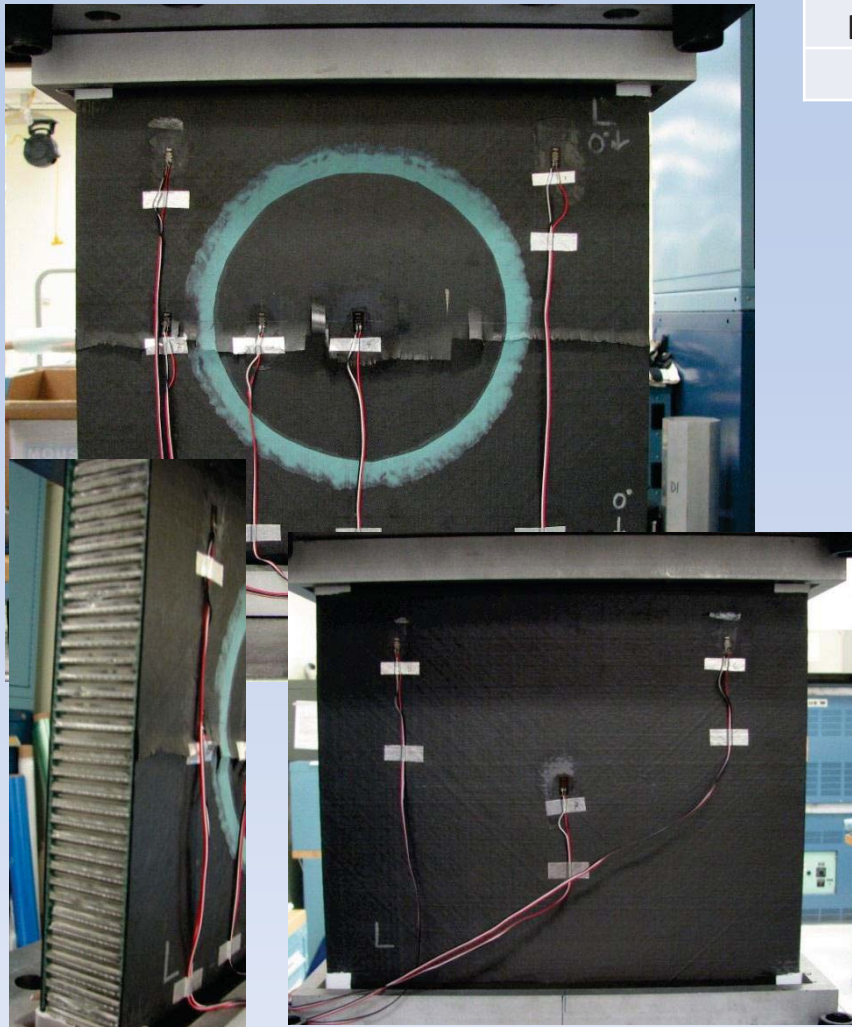
After Repair – Partially Cured Patch



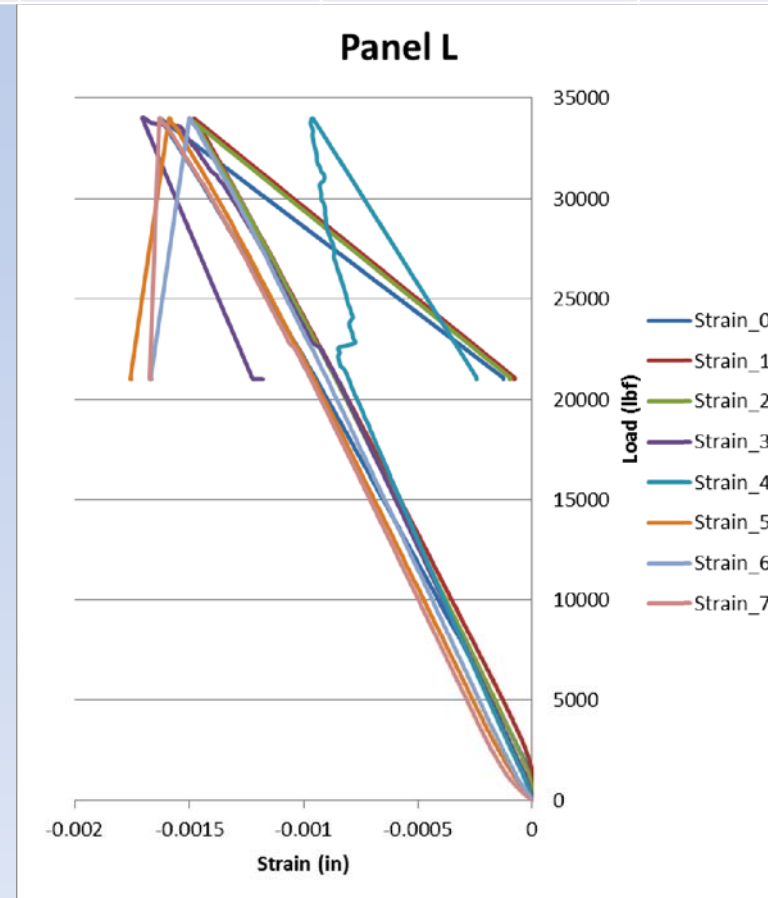
After Repair – Pre-cured Patch



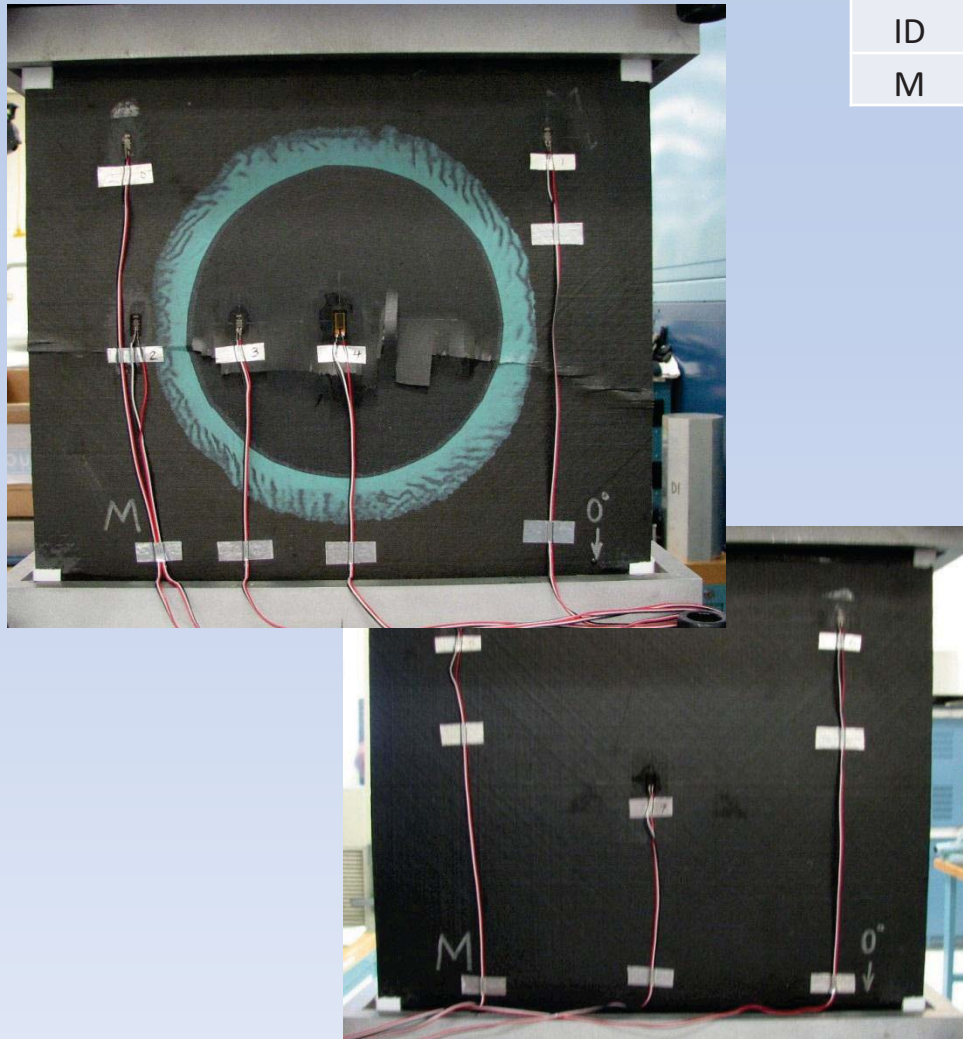
Co-cured Patch



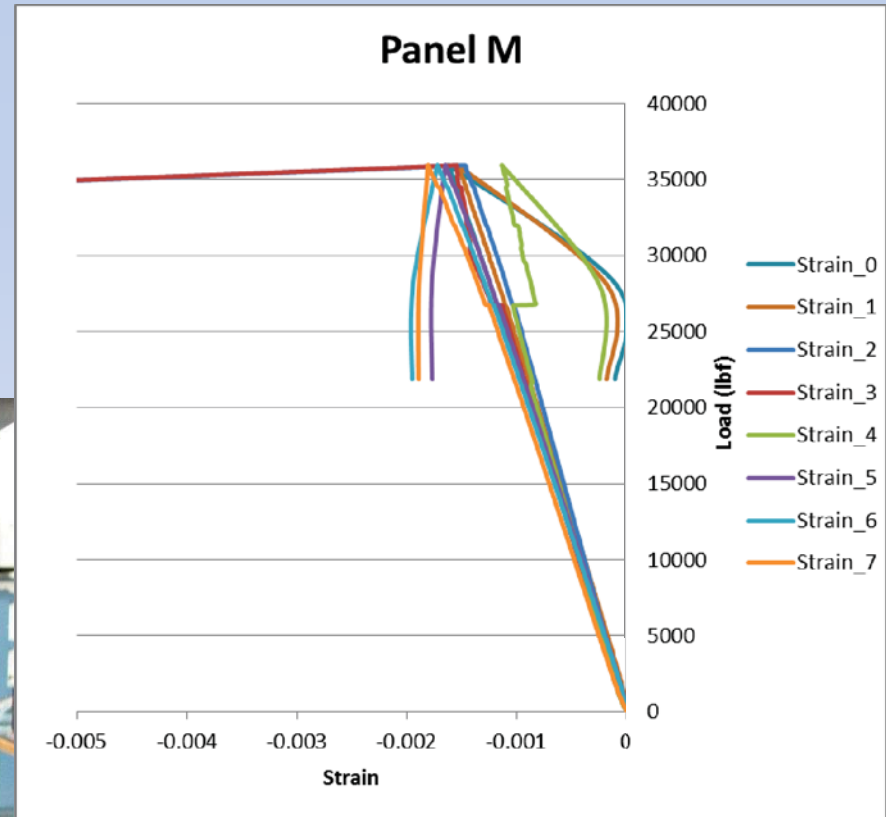
Panel ID	Maximum Compressive Load (lbf)	Compressive Extension at Max Load (in)	Compressive Stress at Max Load (ksi)
L	34111	0.054	34.6



Partially Precured Patch

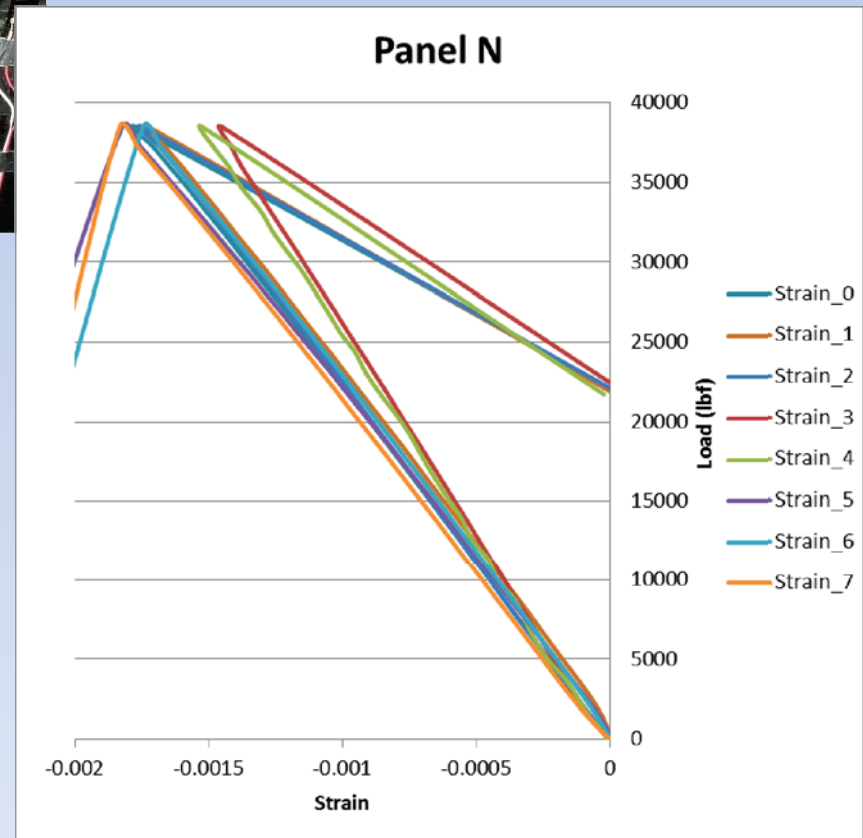
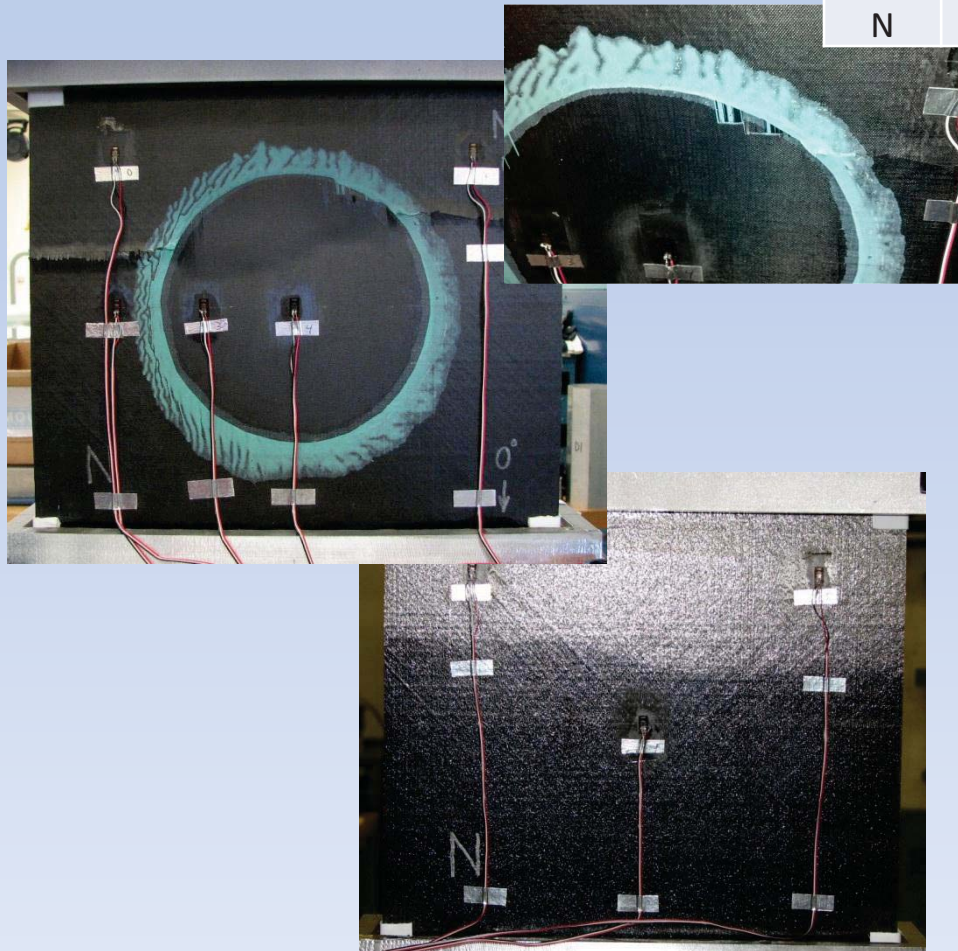


Panel ID	Maximum Compressive Load (lbf)	Compressive Extension at Max Load (in)	Compressive Stress at Max Load (ksi)
M	36117	0.056	36.6



Precured Patch

Panel ID	Maximum Compressive Load (lbf)	Compressive Extension at Max Load (in)	Compressive Stress at Max Load (ksi)
N	38934	0.059	39.5



Summary of Results

Panel ID	Patch Cure Method	Maximum Compressive Load (lbf)	Compressive Extension at Max Load (in)	Compressive Stress at Max Load (ksi)
G	None	51775	0.082	52.4
A	Precured	46608	0.071	47.4
B	Precured	49494	0.075	50.0
C	Cocure	38383	0.059	42.2
D	Cocure	38992	0.059	39.3
L	Cocure	34111	0.054	34.6
M	Partially	36117	0.056	36.6
N	Precured	38934	0.059	39.5

- A comparative study of edgewise compression testing on repaired sandwich panels was completed
- Repairs with precured patches had higher loads than partially cured or cocured patches
 - This may be due to variations in hot bond curing
 - Need more data on partially cured patches

- Test more panels with partial cure patches, incorporating lessons learned from previous work
- Take a closer look at the heating profile of the hot bonder
- Perform repairs on curved panels



Questions?



References

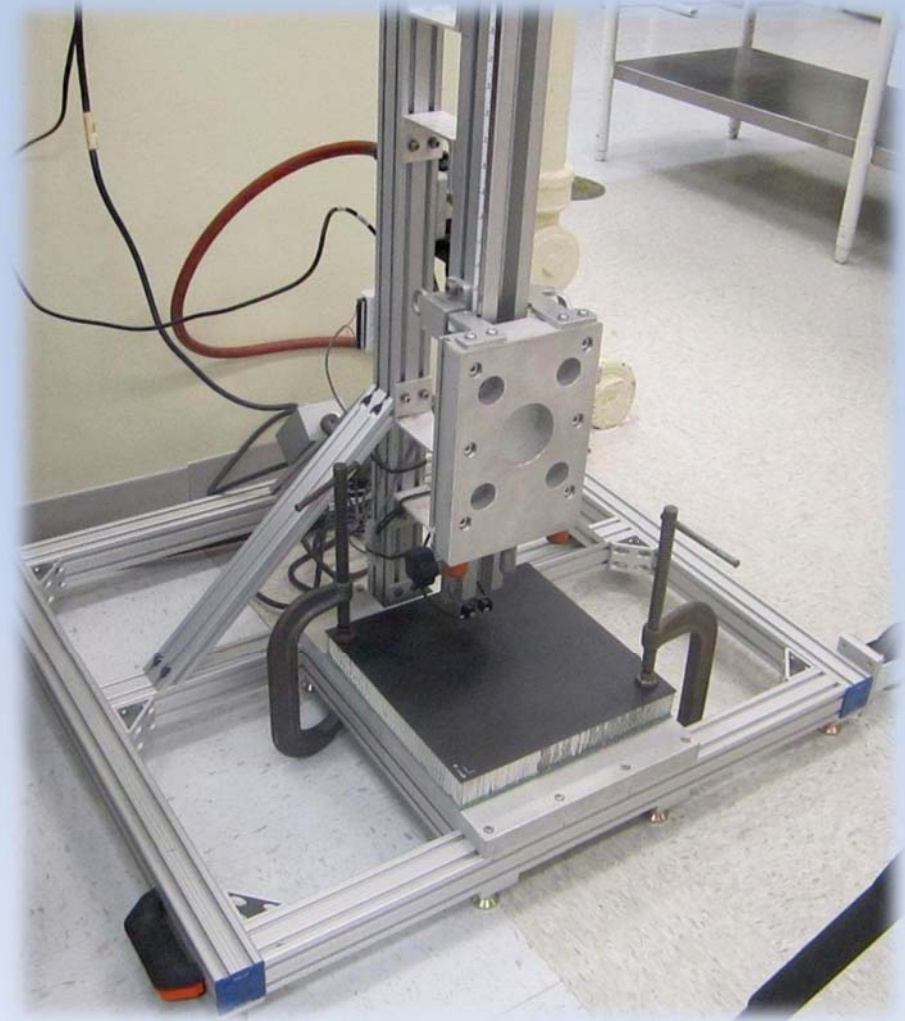


1. Mark J. Shuart, "Composites for Exploration." *SAMPE Conference and Exhibition Presentation*, PowerPoint. May 21-24, 2012
2. Douglas A. McCarville, et. al. (2013) "Manufacturing Overview of a 2.4 Meter Composite Cryotank." *SAMPE Conference Proceedings*, Long Beach, CA, May 6-9, 2013.
3. Keller, R.L., Owen, W.S. "Process method to repair bismaleimide (BMI) composite structures." (2004). *US Patent Number 6761783*.
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4. Keller, R.L. and Spalding, J.F. "Process development protocol and vacuum bag process for carbon-epoxy prepreg." *US Patent Number 7857925*.
<https://www.google.com/patents/US7857925>



Backup

Impactor





Vehicle

Heavy Lift

Atlas V

Delta IV

Dia

10 m

5.4 m

5.1 m

Area

~561 m²

~311 m²

~277 m²

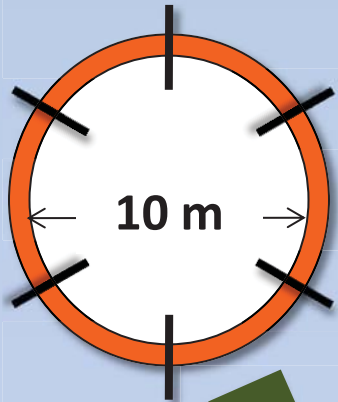
- A Multi-center team with the goal of developing a 10 m diameter payload fairing
- Demonstrate 25-30 percent weight savings and 20-25 percent cost savings for composite compared to metallic payload fairing structures

CoEx Thrust	SOA
Panels for 10-m-dia. barrels	No composites experience at this scale
Automated manufacturing	Limited to 7-m-dia. barrels
OoA* technologies	Maturing for aerospace quality
Design database	Not demonstrated for 10-m-dia. barrels

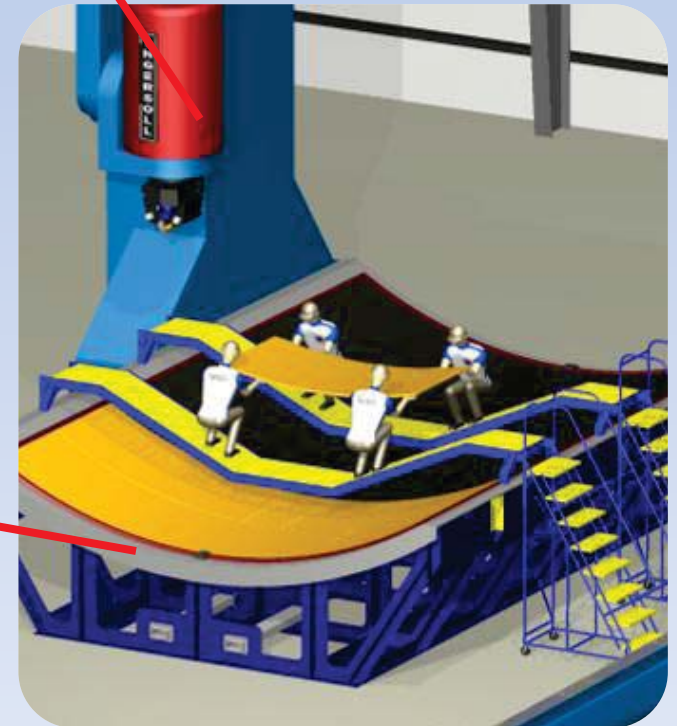
***out of autoclave**



1/6th – Arc Panel Fabrication



Automated Fiber Placement System



1/6th Tool Fabrication

Panels Not Completed



Panel E



Panel F