Repair Development for a Composite Cryotank

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Agenda

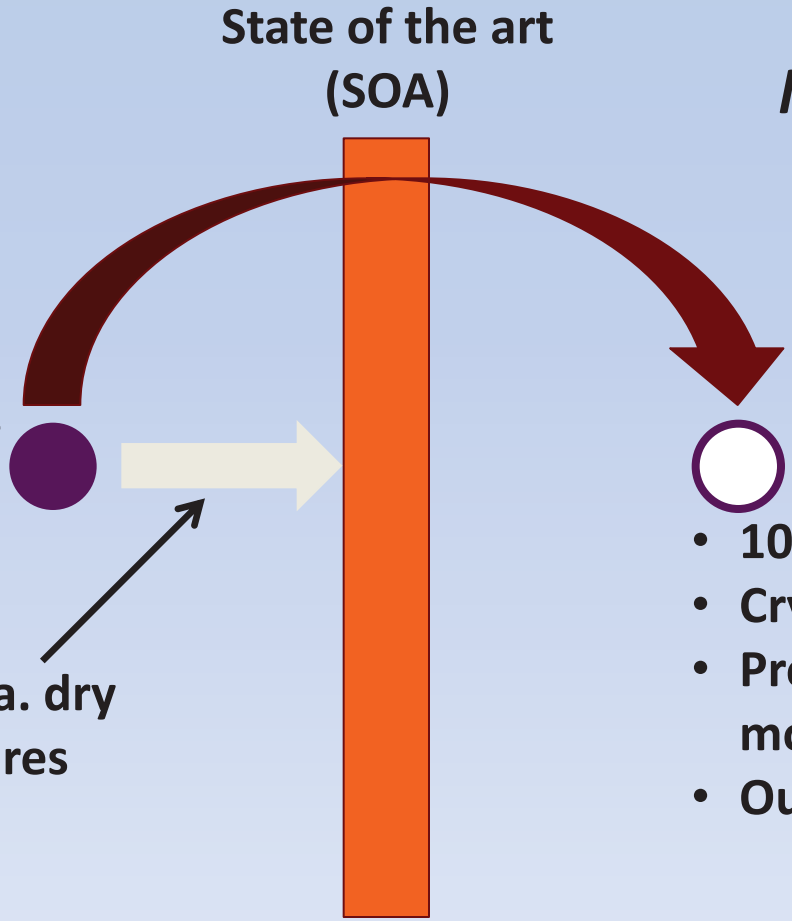
- Background of Composites and Composite Cryotank Project
- Sandwich Panel Fabrication
- Repair Development and Testing

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

Strategy for Development

Leapfrogging the SOA puts NASA in a leadership position to drive technology development



NASA's experience with composite primary structures for launch vehicles

- **5-m-dia. dry structures**

- **10-m-dia. structures**
- **Cryotanks**
- **Pressurized habitation modules**
- **Out-of-autoclave processing**

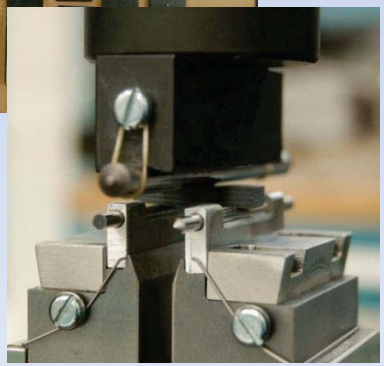
Composite Cryotank Technologies and Demonstration

- 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 LH_2 composite cryotanks
- KSC Objectives
  - Understand the properties of the composites
  - Perform hands on repair work at KSC
  - Develop out of autoclave repair cure process

Material Property Testing

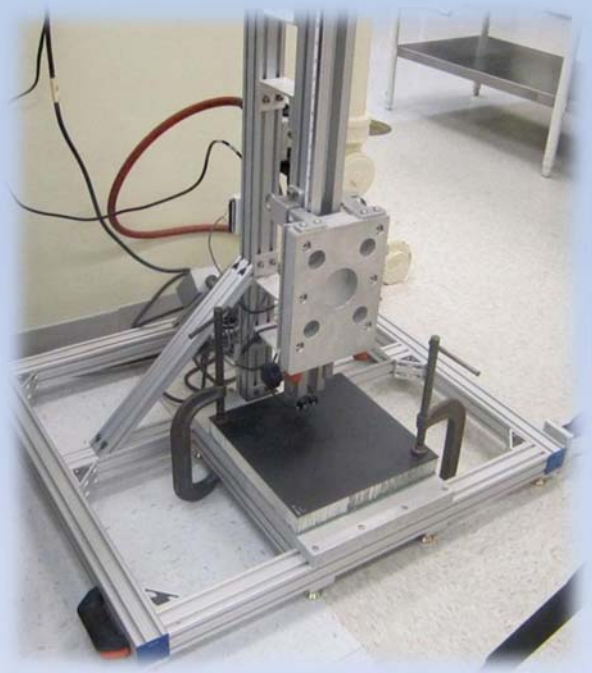
- Void Analysis
  - Microscopy
  - Combustion
  - Compared with Acid Digestion at Glenn
- Mechanical Testing
  - Tensile
    - 16 ply specimens, all in the same direction
  - Short Beam Shear
    - 32 ply specimens, all in the same direction

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



Phase I: Repair Sandwich Panels

Face Sheets

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

Core

- 1.5” Aluminum Honeycomb
- FM-300 Film Adhesive

Repair Patch

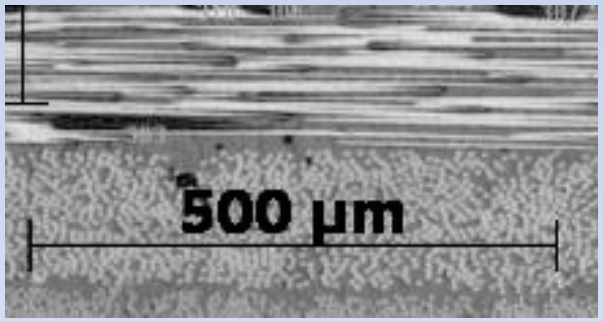
- HR40/5320-1 Unitape Prepreg
- FM-300 Film Adhesive

Core Plug

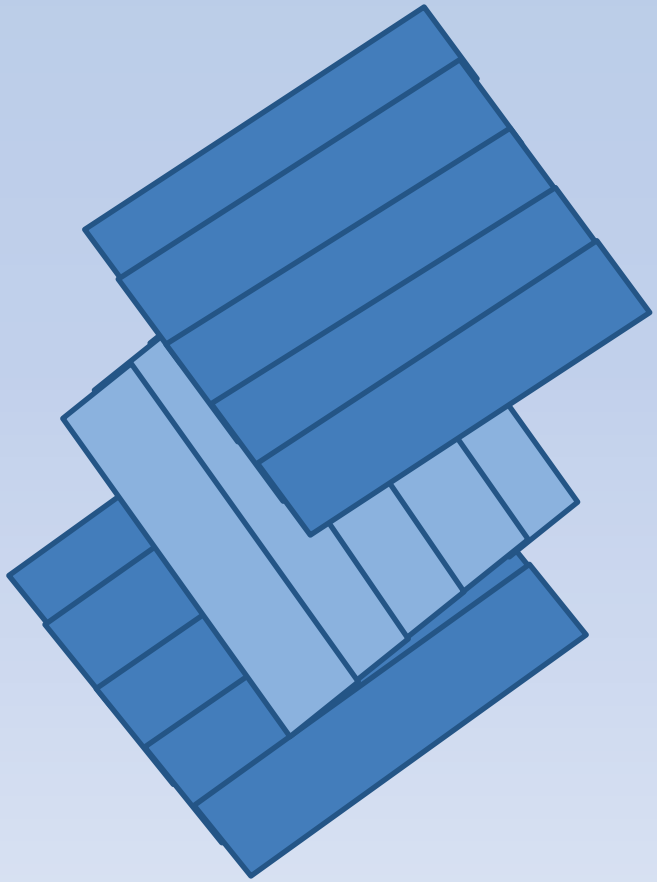
- 1.5” Aluminum Honeycomb
- Hysol MA 562 Foaming Adhesive
- FM-300 Film Adhesive

Composite Panel Fabrication

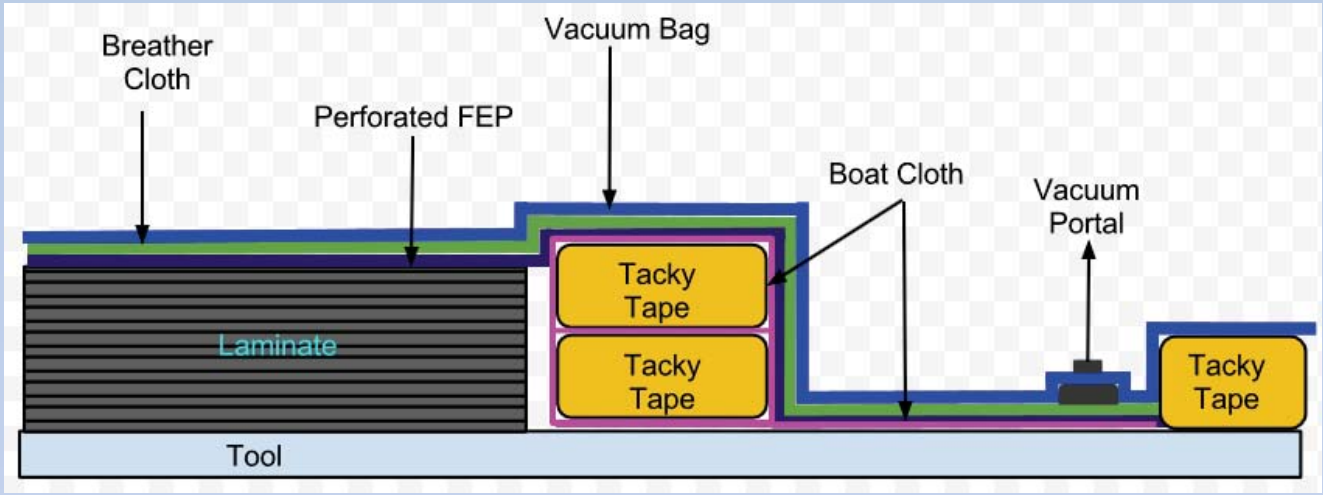
- HR40/5320-1 Prepreg Unitape
  - Fibers preimpregnated with resin
  - Hand Layup onto flat tool
  - Out of Autoclave curing



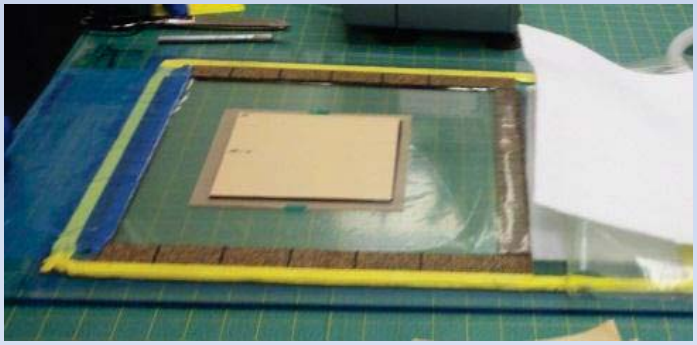
[0,90] Composite Microscopy Image



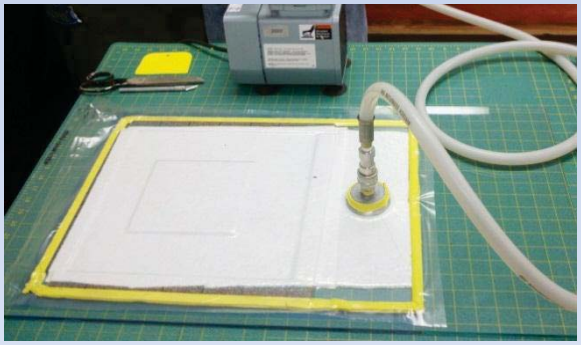
Composite Panel Fabrication



The Panels Are Made by Hand Lay-up Method



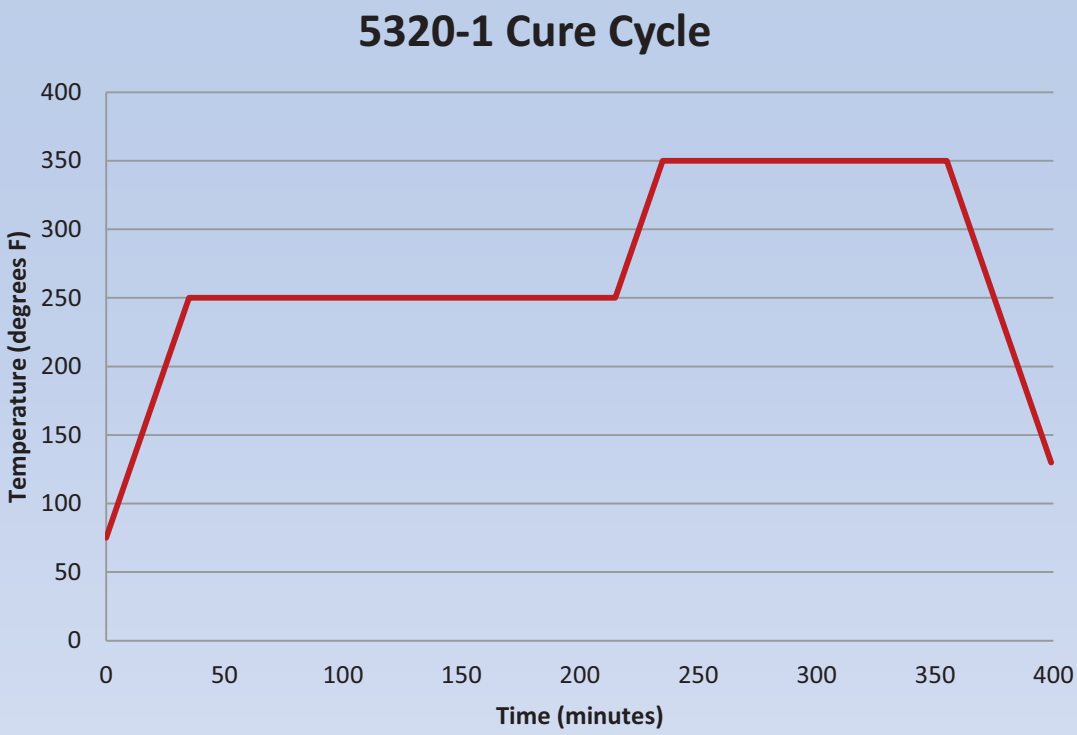
Prepreg Sheets Hand Lay-up



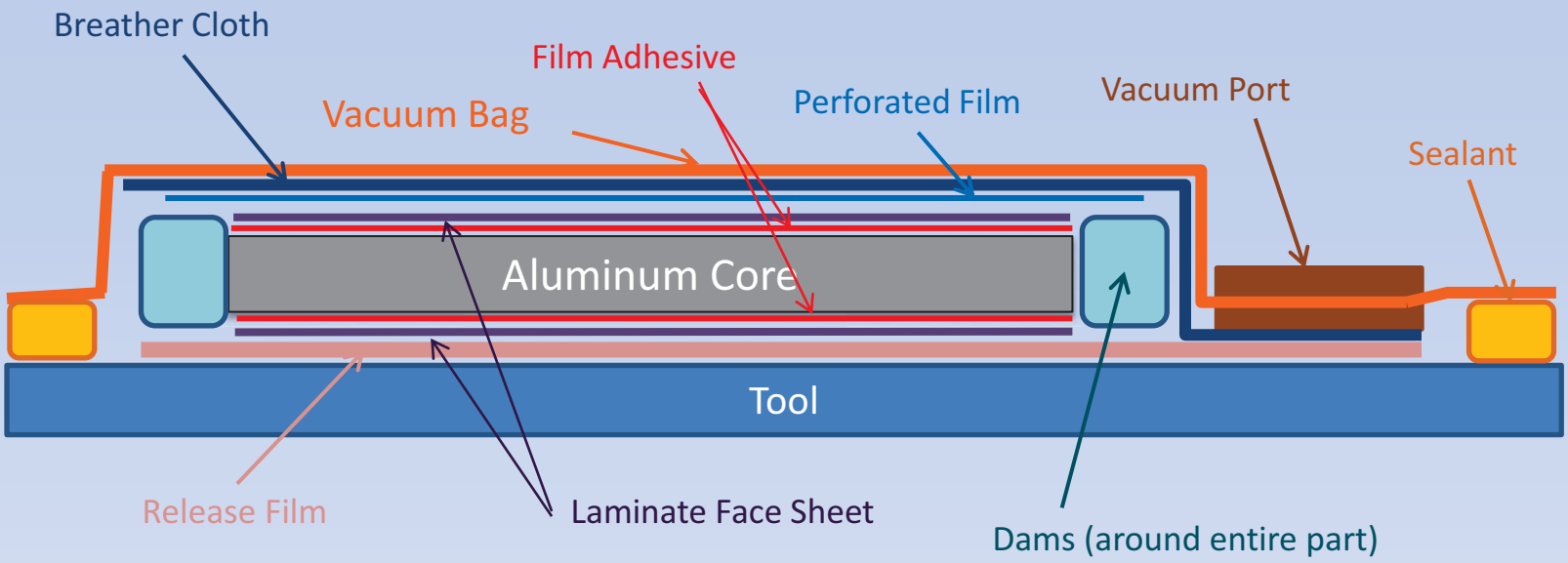
Vacuum Debulk of Composite Panel

Oven Cure of Panel Under Vacuum

5320-1 Cure Cycle

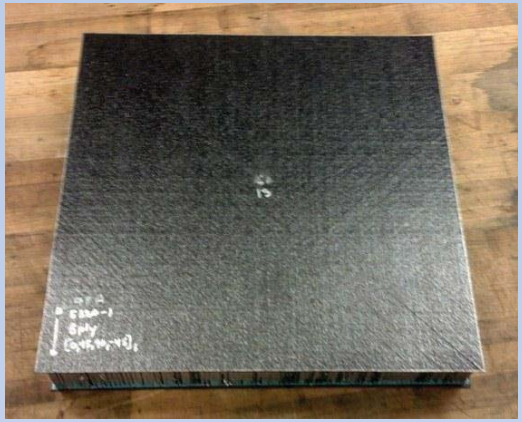


Sandwich Panel Fabrication



Sandwich Panels after Impact

Panel A

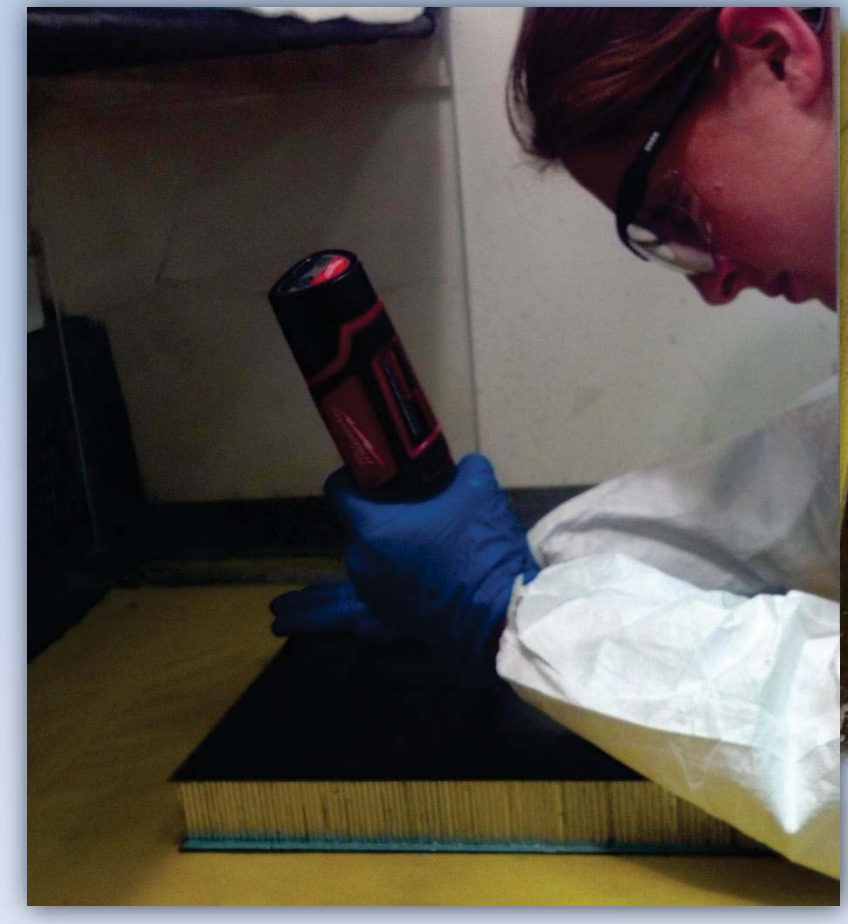


Panel C

Panel B

Panel D

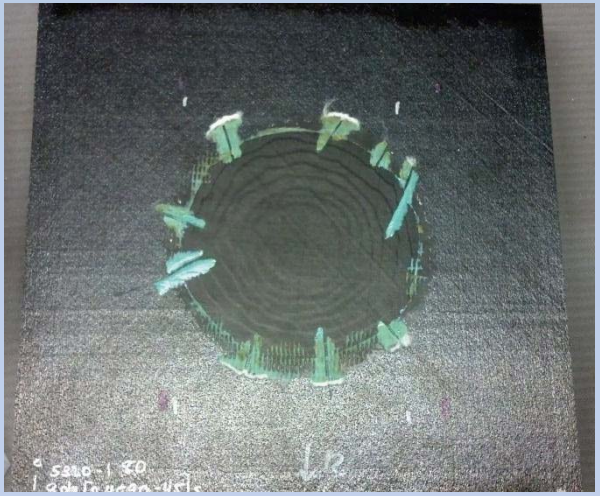
Sandwich Panel Scarfing



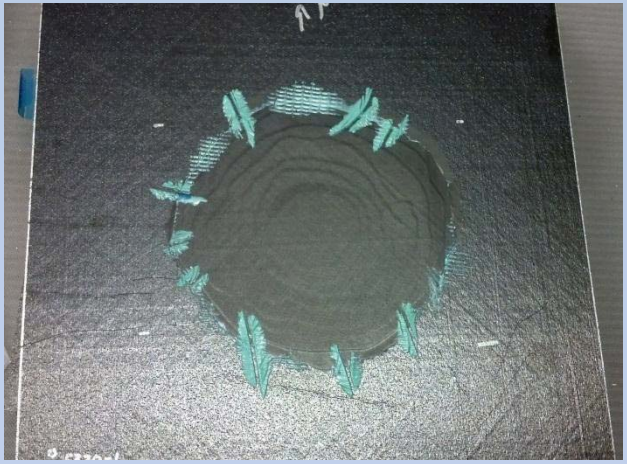
Patch Preparation Methods

- 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

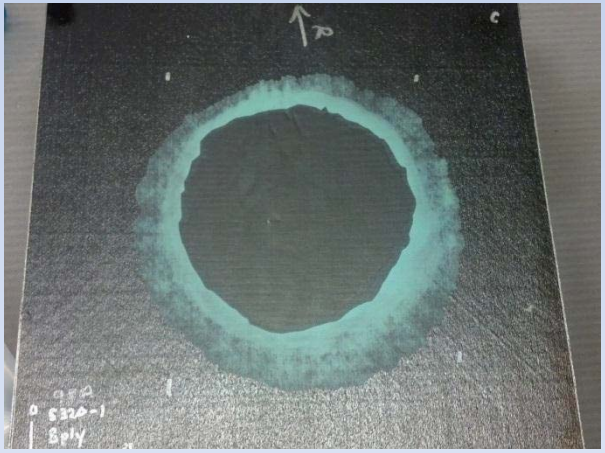
Repaired Panels



Panel A: Pre-cured Patch



Panel B: Pre-cured Patch



Panel C: Co-cured Patch

Panel D: Co-cured Patch

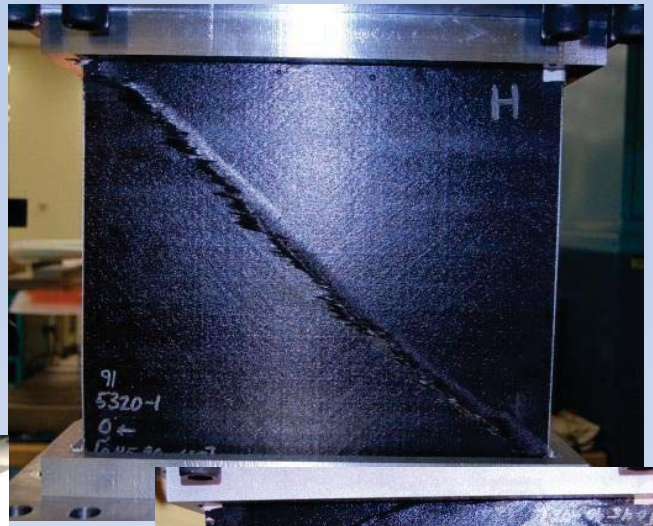
Edgewise Compression Testing

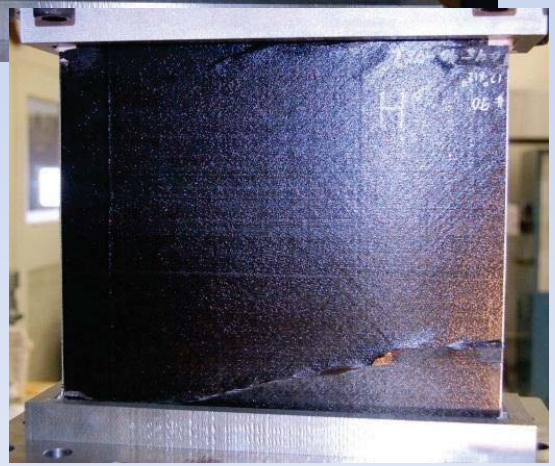
- ASTM C 364: Standard Test Method for Edgewise Compressive Strength of Sandwich Constructions
- Provides a load carrying capacity of the construction of the sandwich panels after a repair has been performed.
- Panels potted into end caps

Edgewise Compression Testing

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		

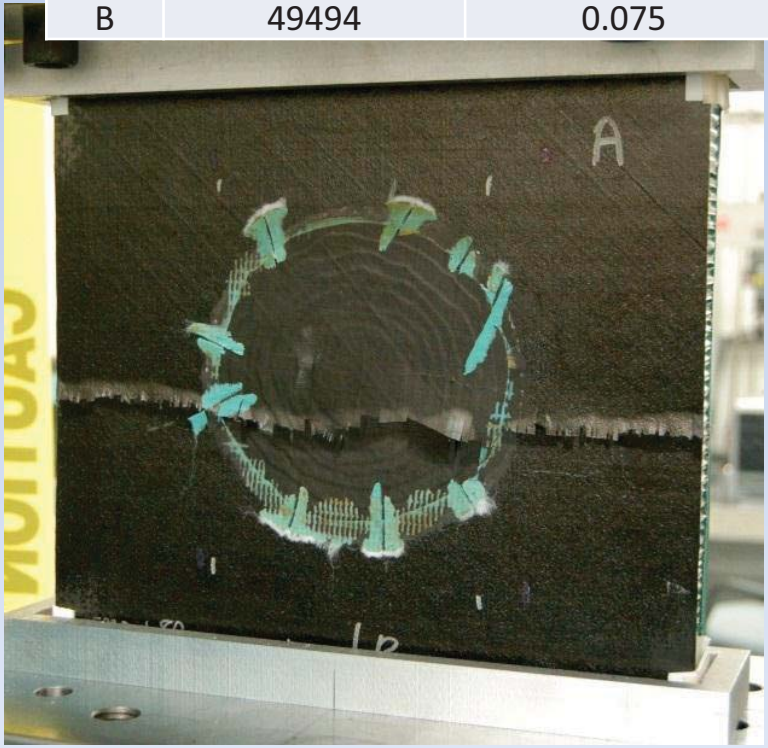


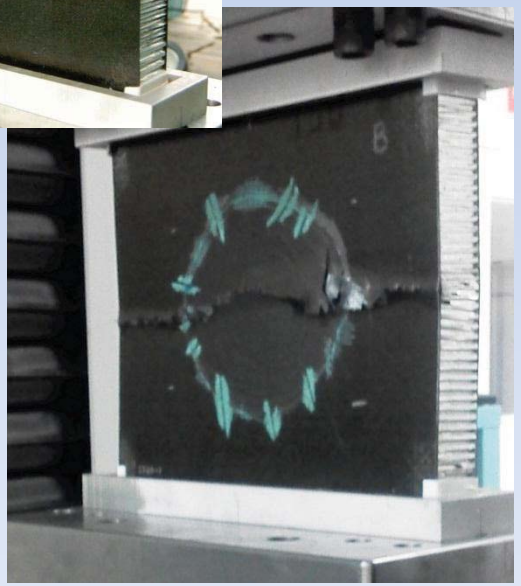


Edgewise Compression Testing

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

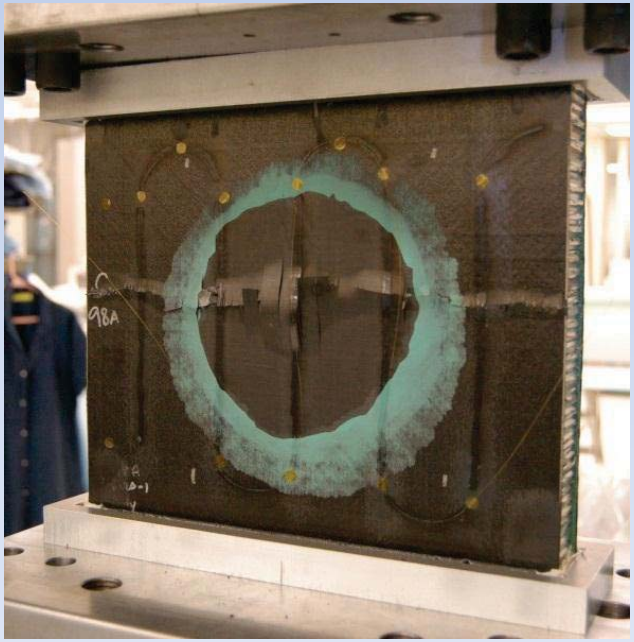


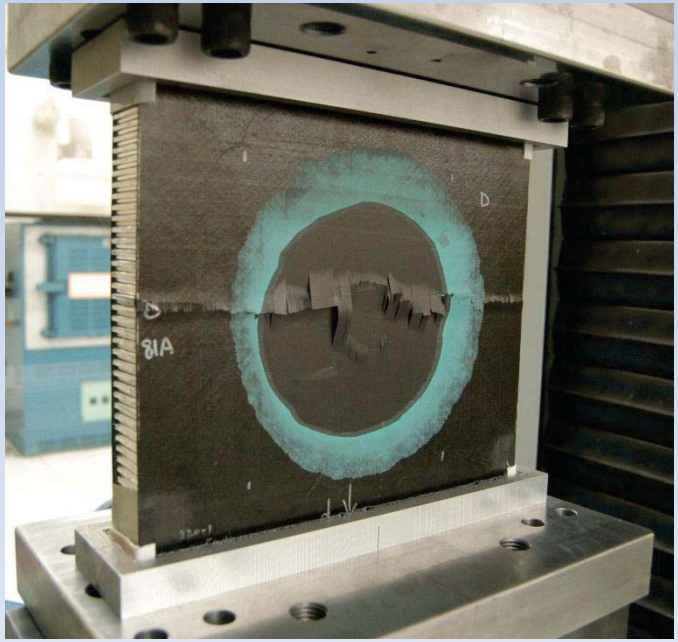


Edgewise Compression Testing

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



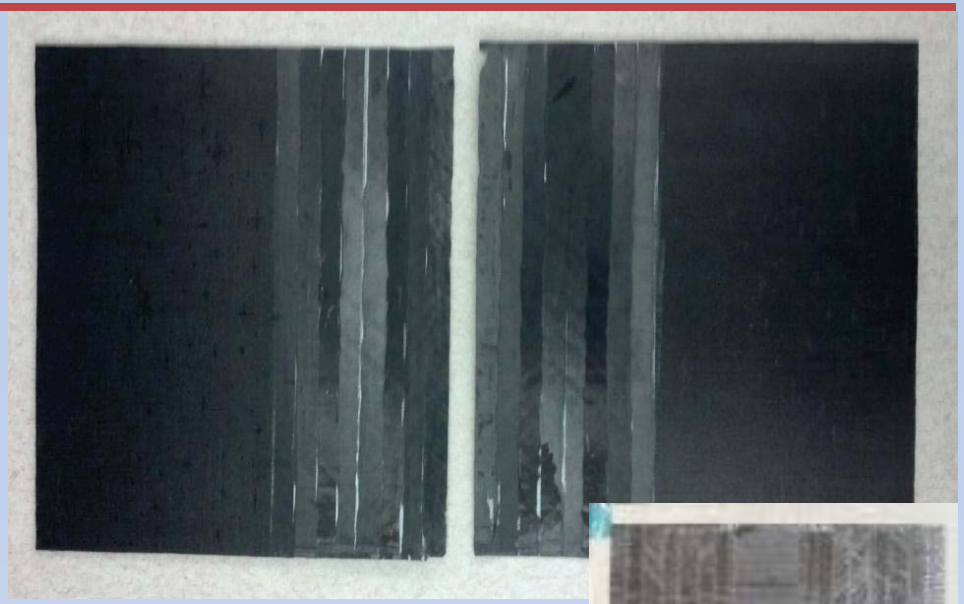


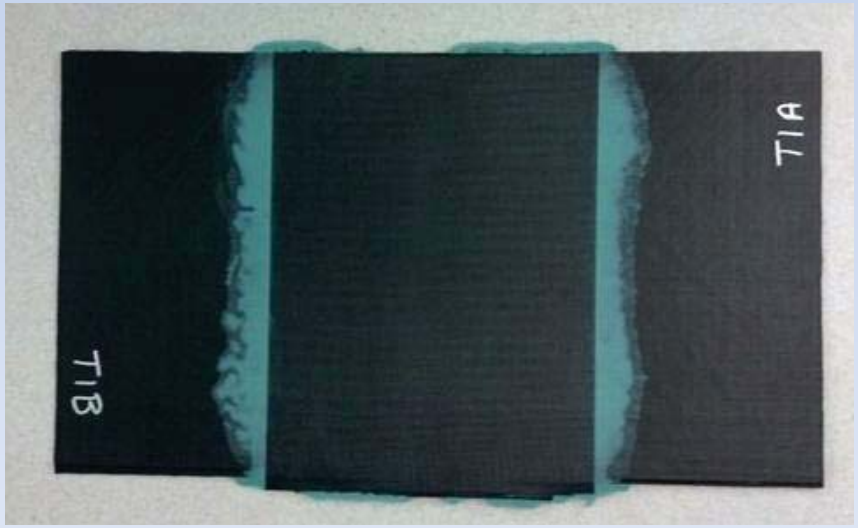
Phase IA: Partially Cured Patches

- 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

Phase IA: Partially Cured Patches

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





Patch Cures

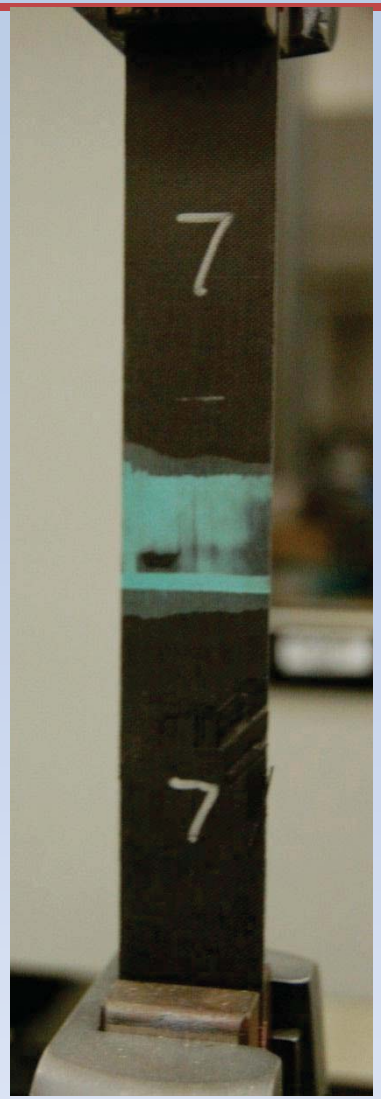
- Patches cured in oven under vacuum at the temperature and time given
- All patches were de-bulked on the part for 30 minutes prior to hot bond cure
- Repairs cured on hot bonder at 250°F for time shown and then at 350°F for 2 hours

Sample ID	Cure in Oven		Hot Bonder
	Temp (deg F)	Time (min)	Cure Time at 250F (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

Tensile Testing

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

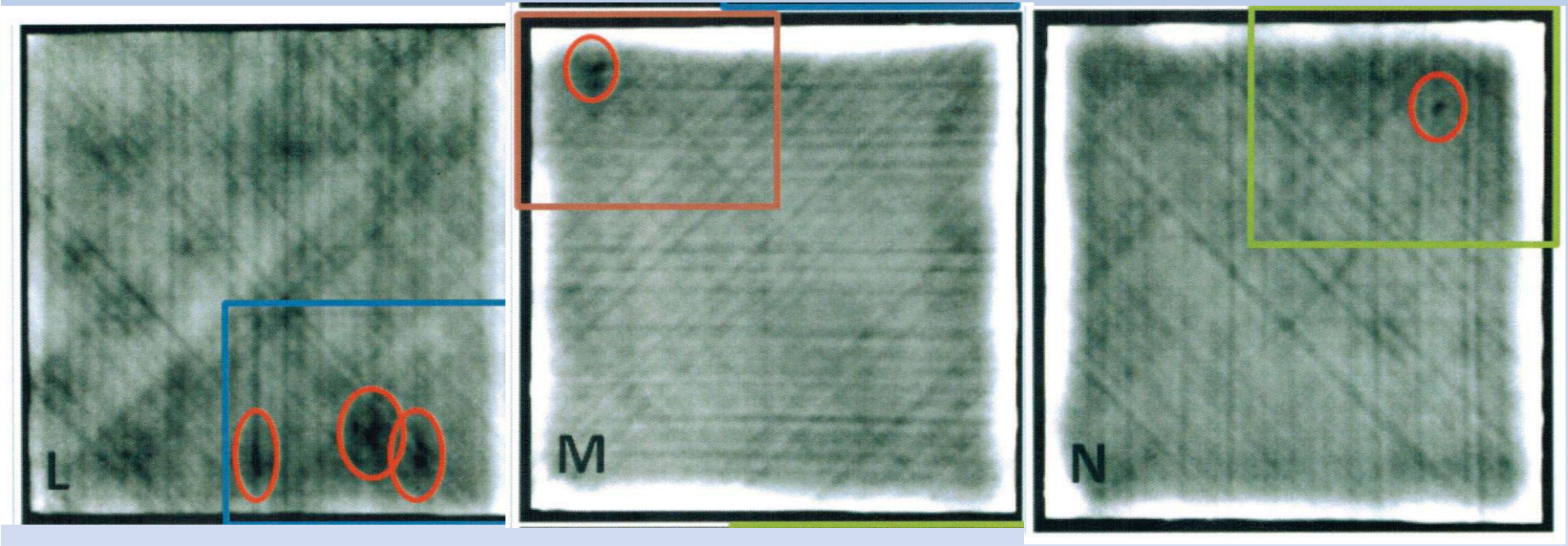
Sample ID	Cure in Oven		Hot Bonder Cure Time at 250F (min)	Observations After Oven Cure	Average Tensile Strength (psi)
	Temp (deg F)	Time (min)			
1-AB	150	15	165	Patch was still tacky, pliable	38107
1-CD	150	30	150	Patch was still tacky and pliable	38689
2-AB	150	60	120	Patch was not very tacky or pliable	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

Initial IR Thermography Scan

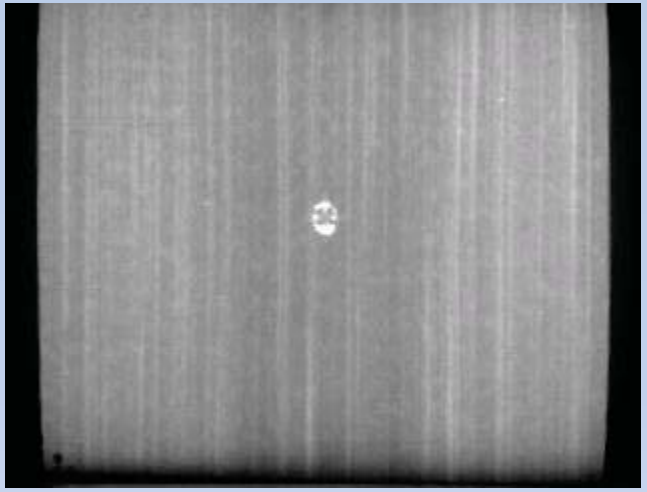


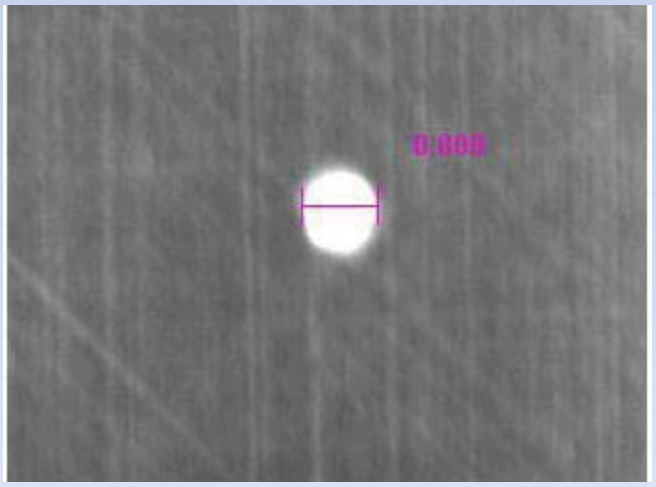
Planned for Co-cured patch

Planned for partially cured patch

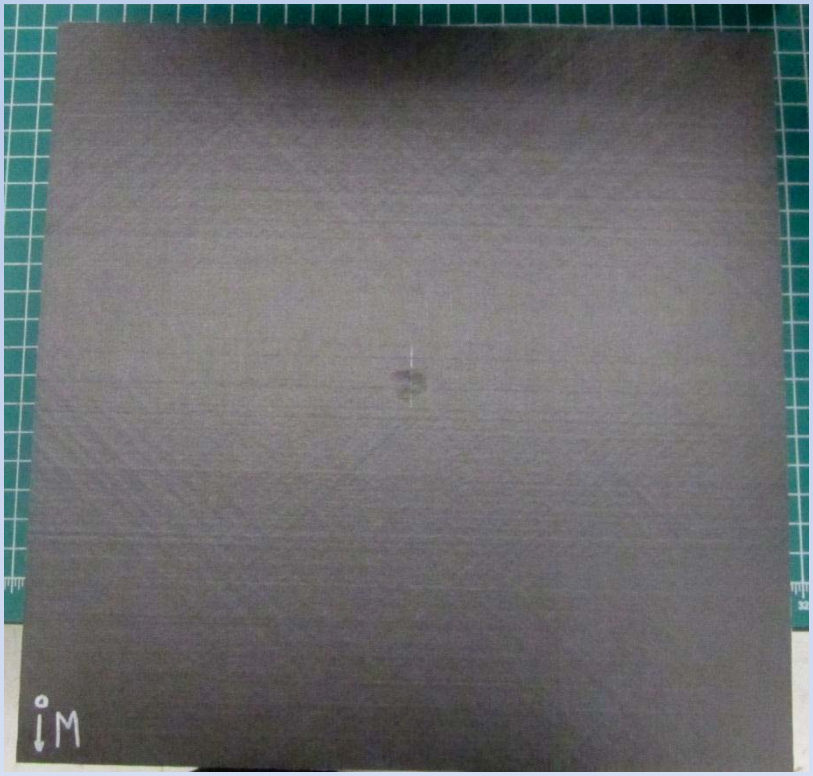
Planned for pre-cured patch

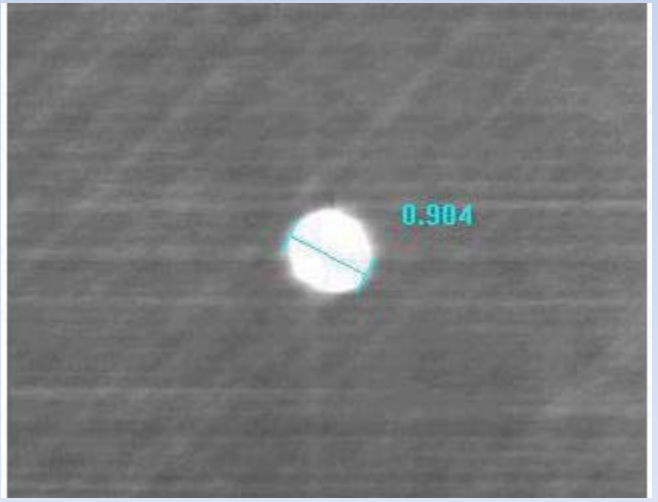
After Impact



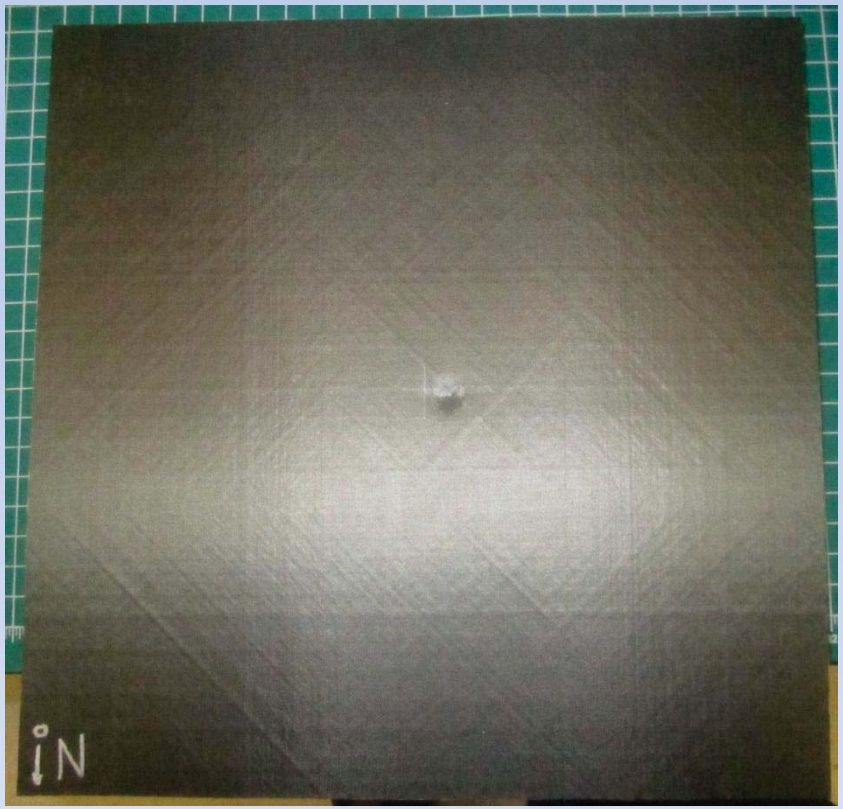


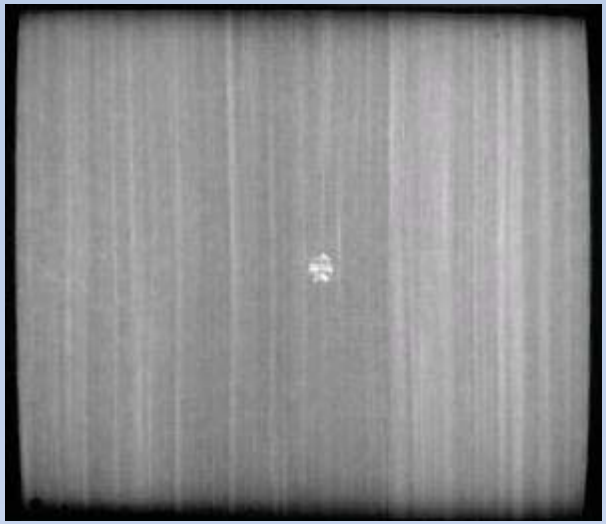
After Impact

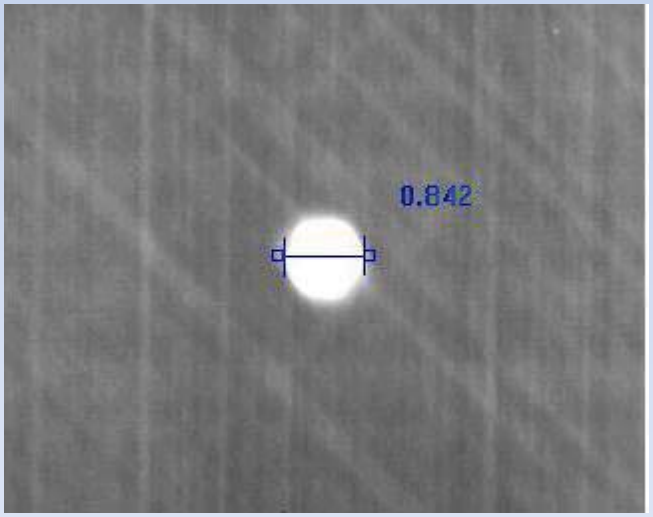




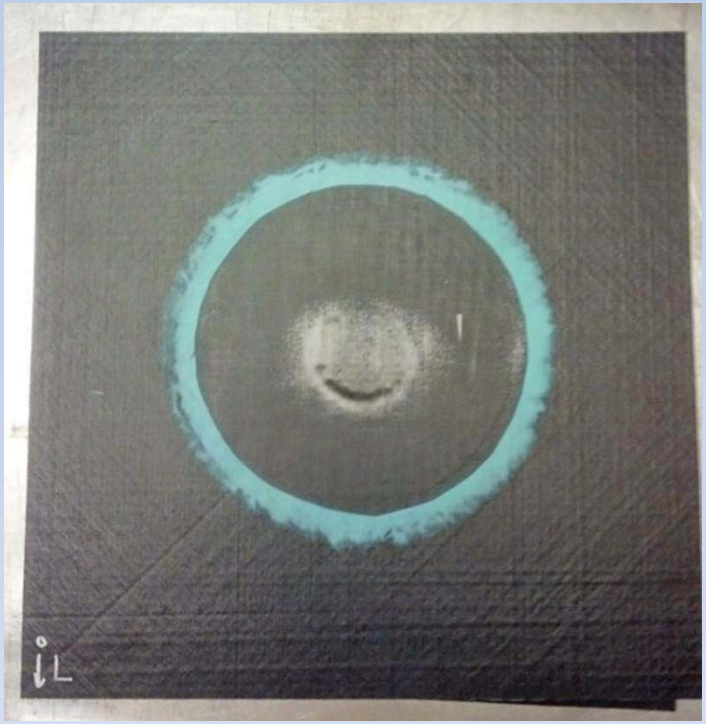
After Impact

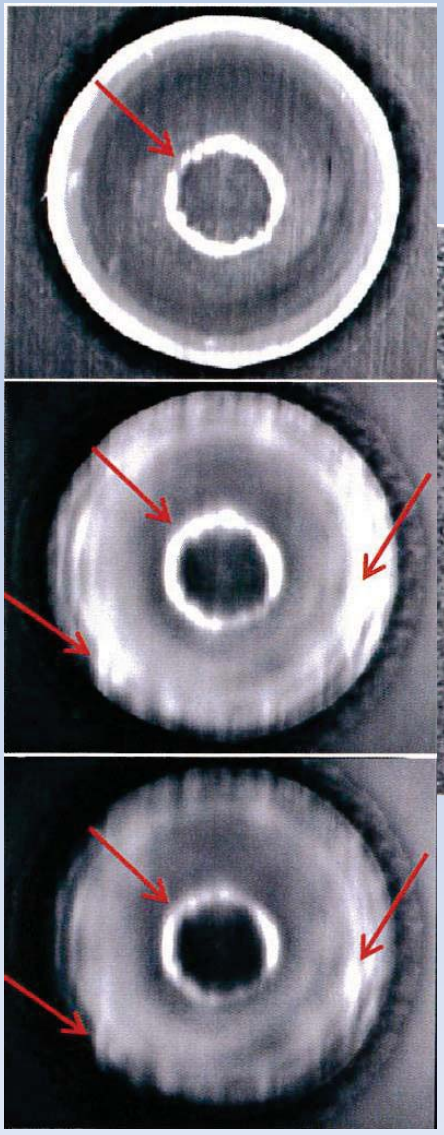


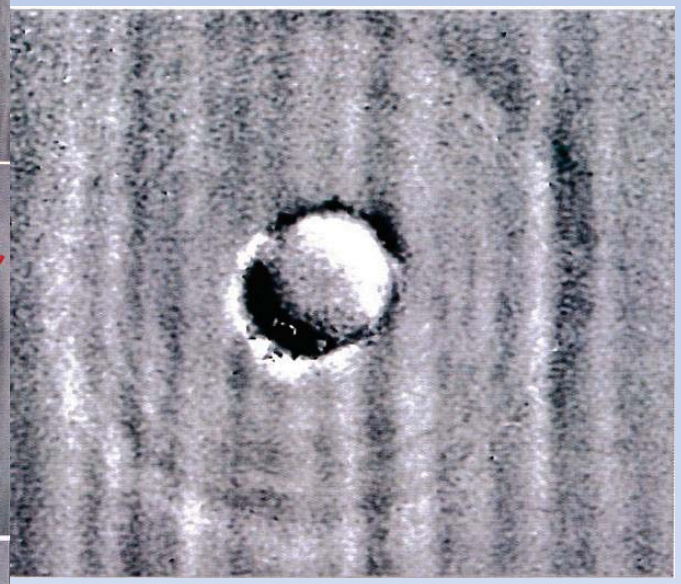




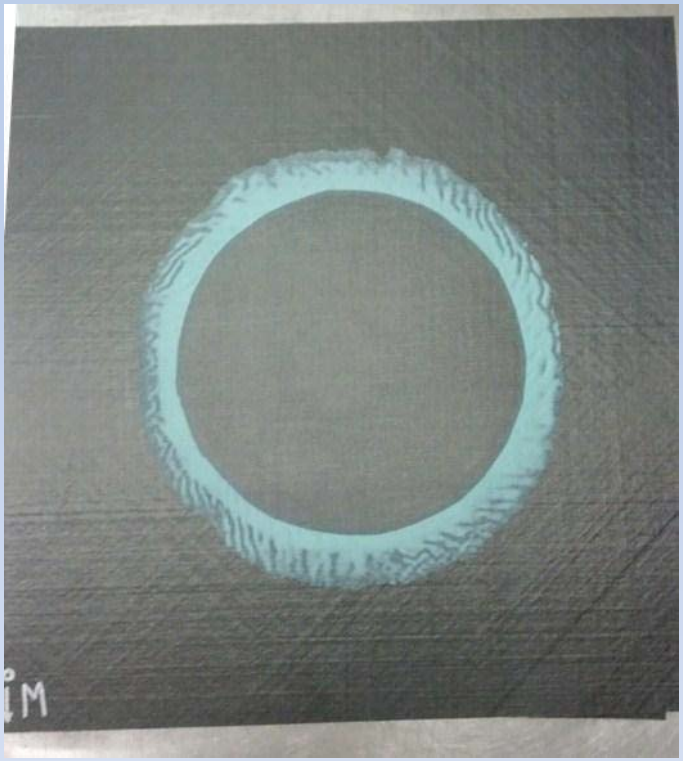
After Repair – Co-cured Patch

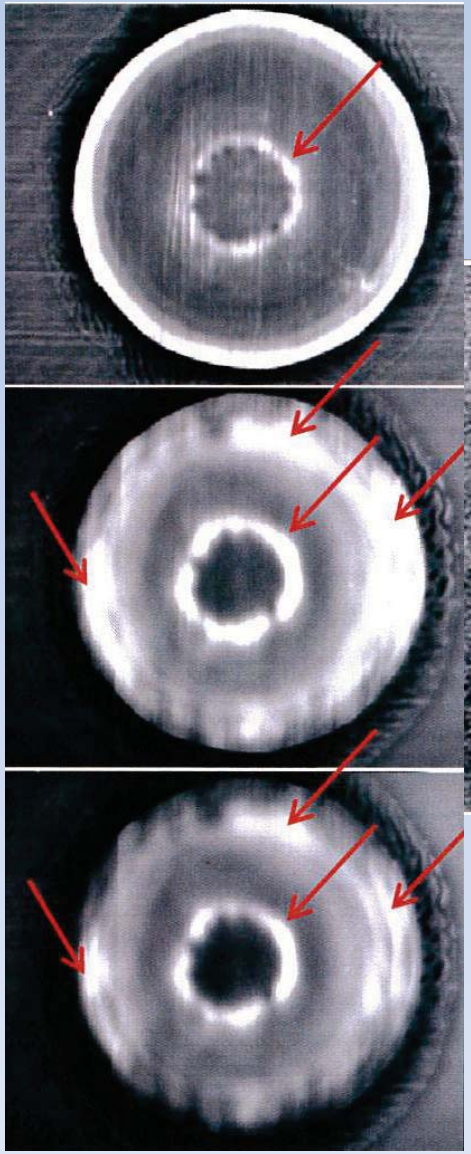


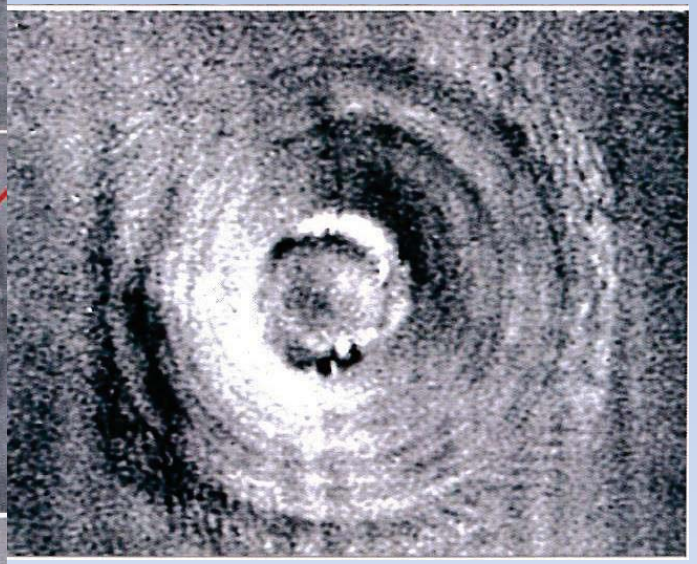




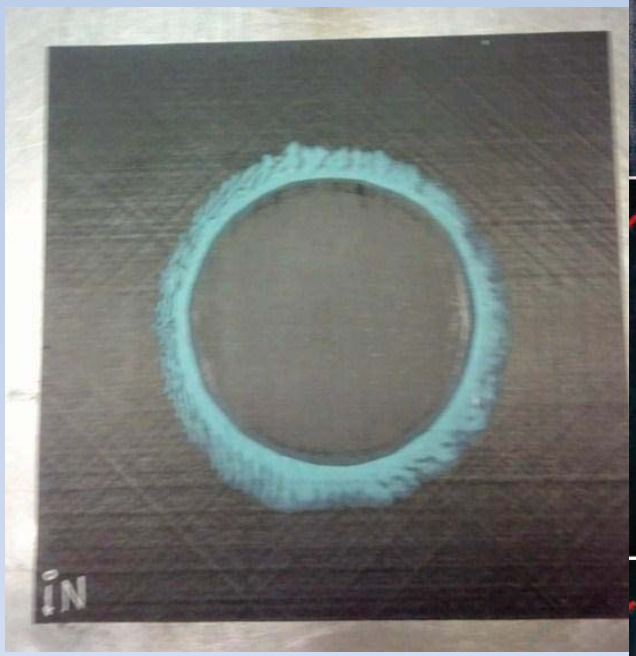
After Repair – Partially Cured Patch

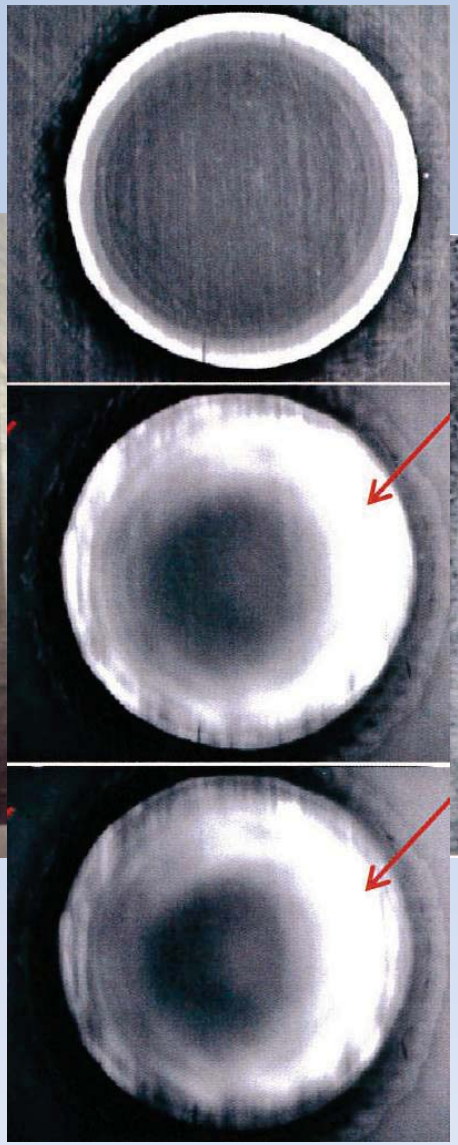


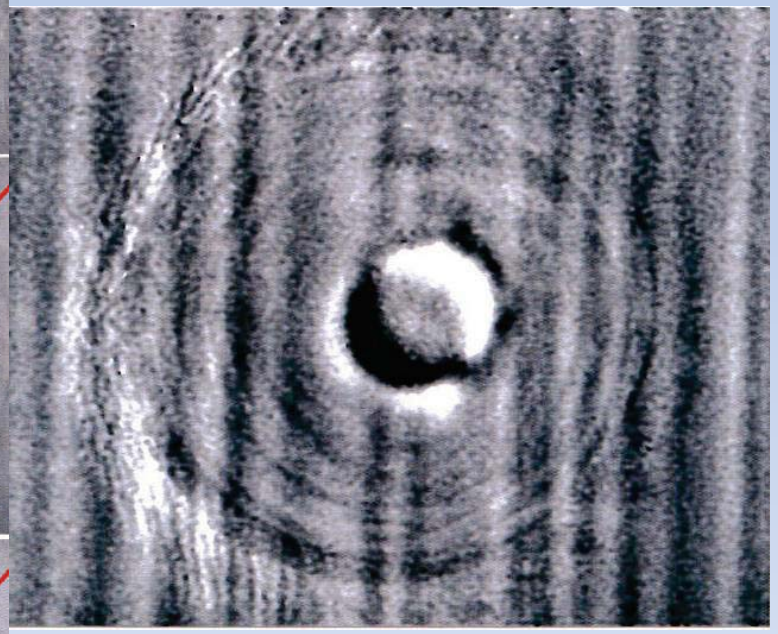




After Repair – Pre-cured Patch

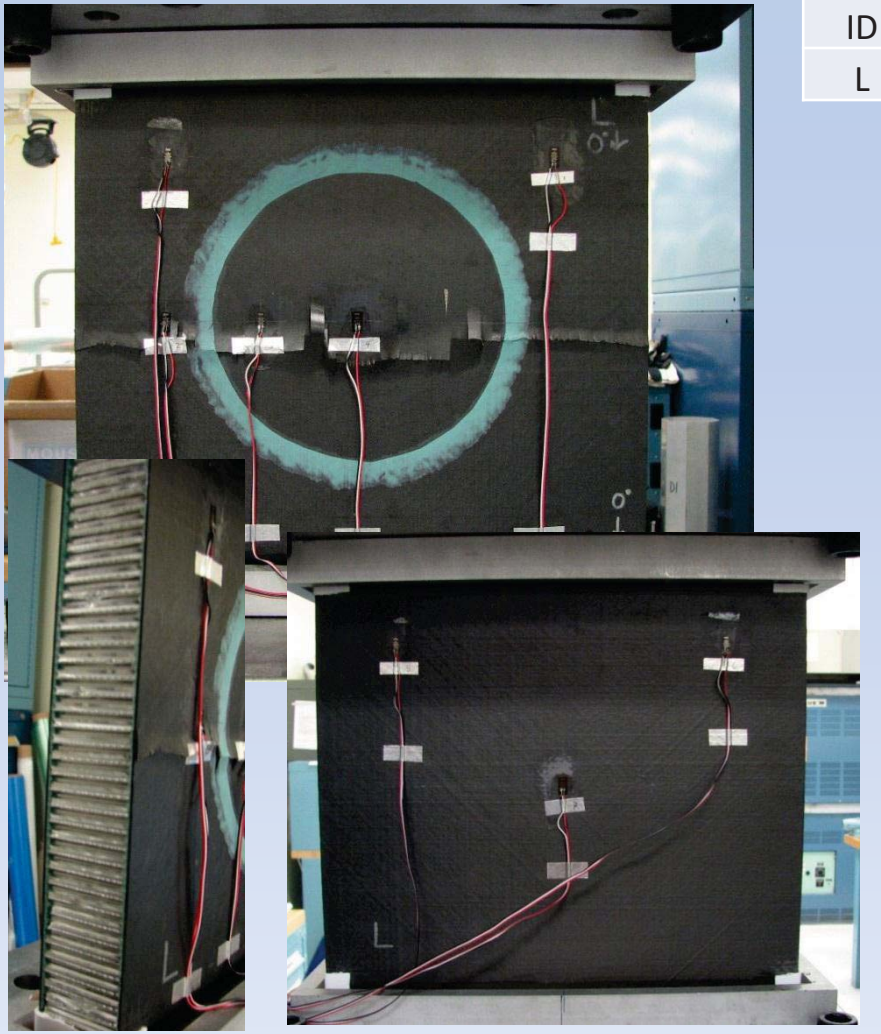




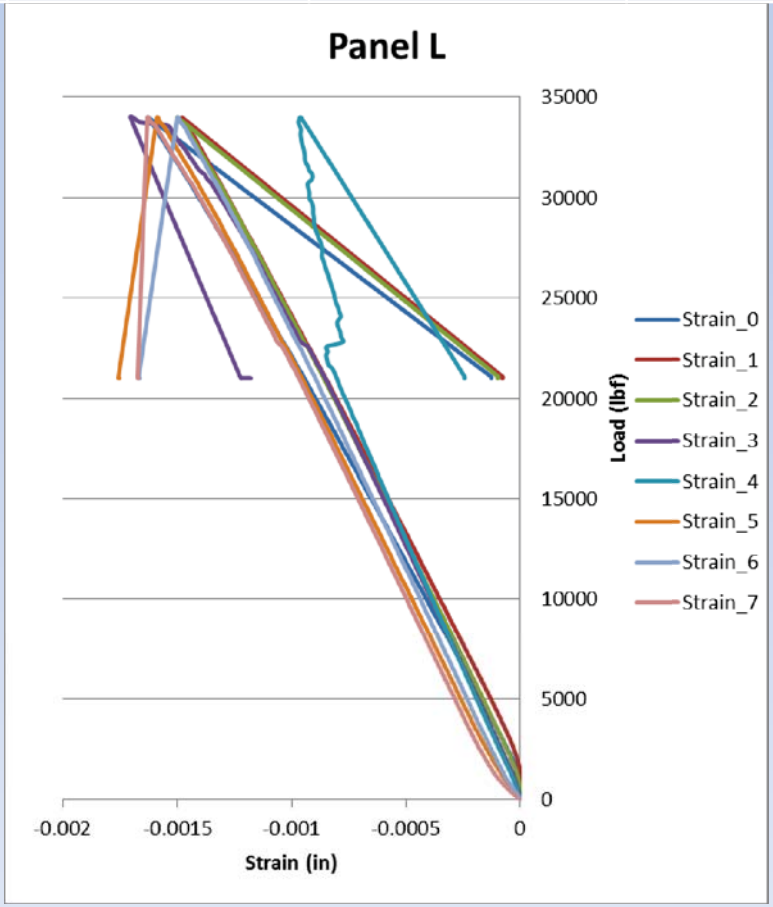


Edgewise Compression

Co-cured Patch



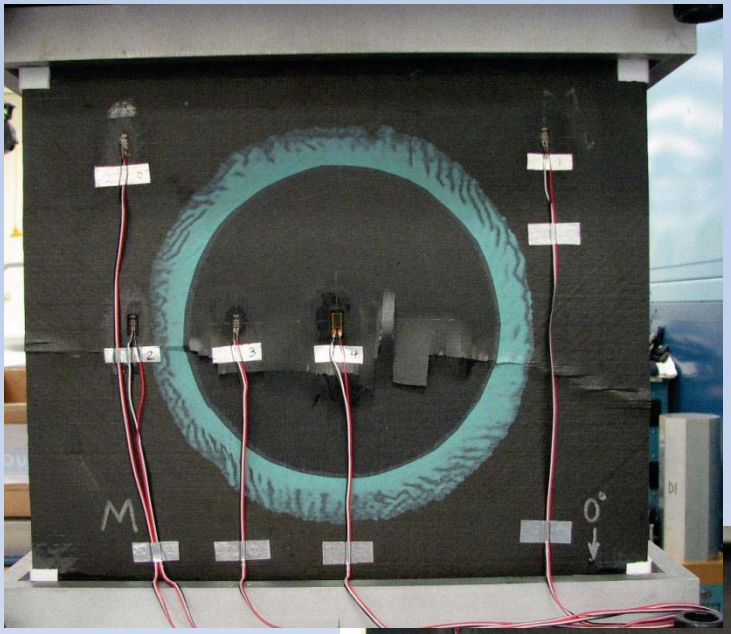
Panel ID	Maximum Compressive Load (lbf)	Compressive Extension at Max Load (in)	Compressive Stress at Max Load (ksi)
L	34111	0.054	34.6

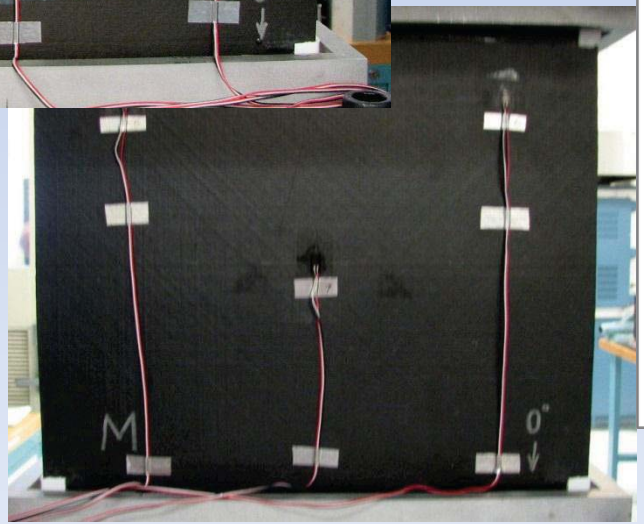


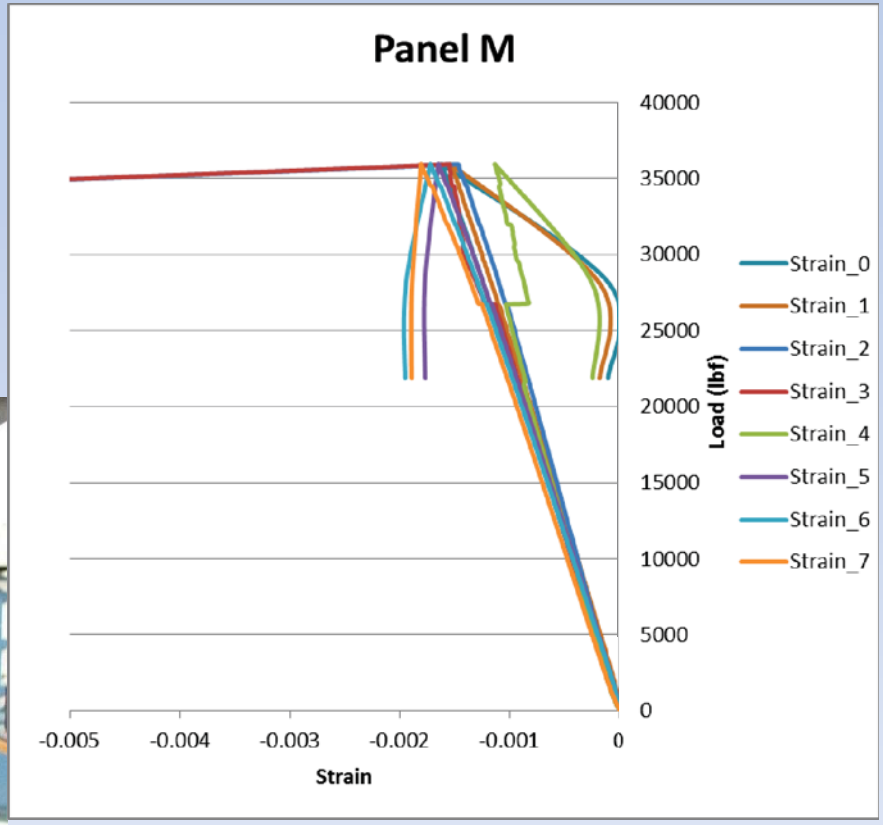
Edgewise Compression

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



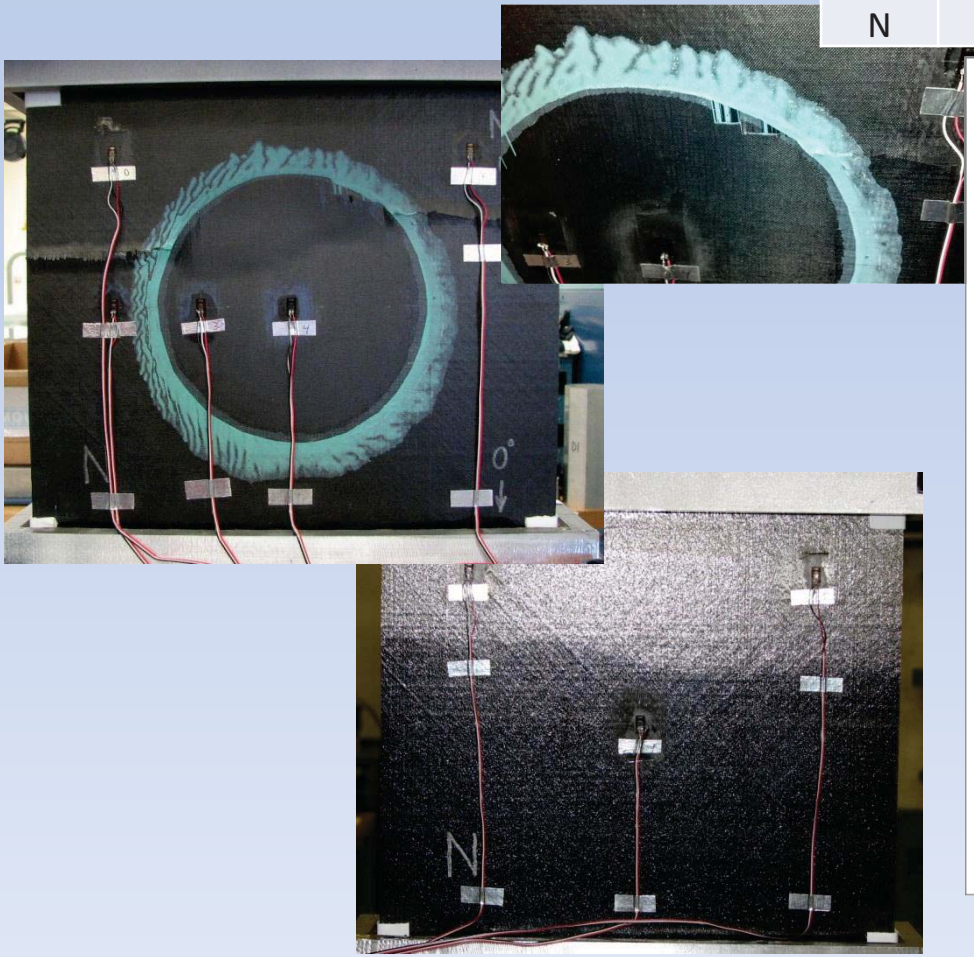


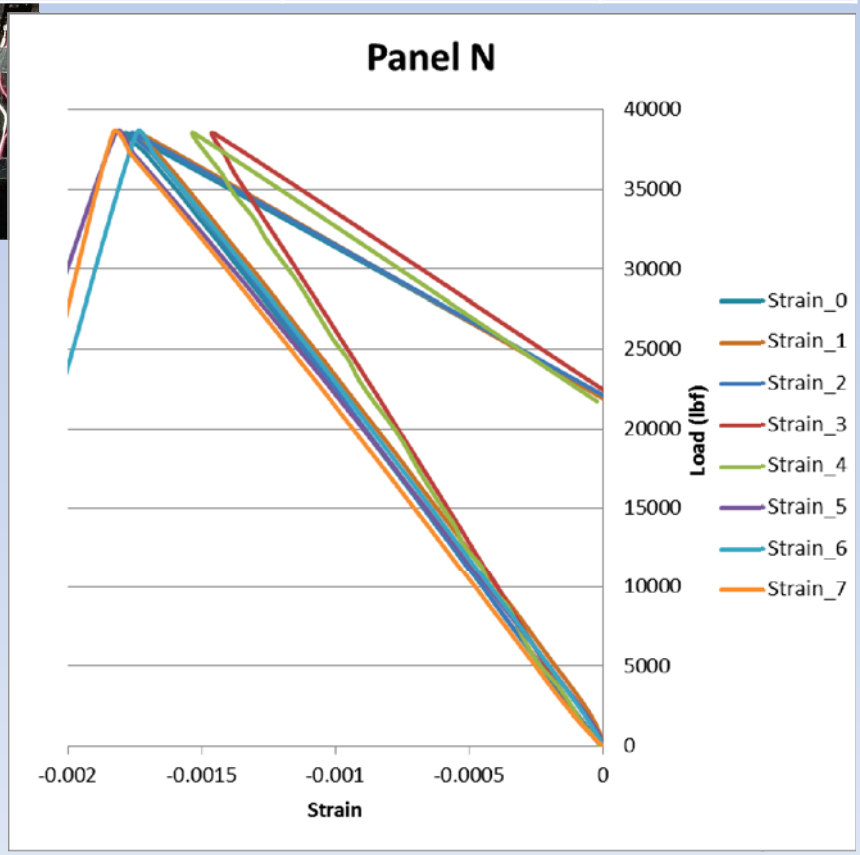


Edgewise Compression

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

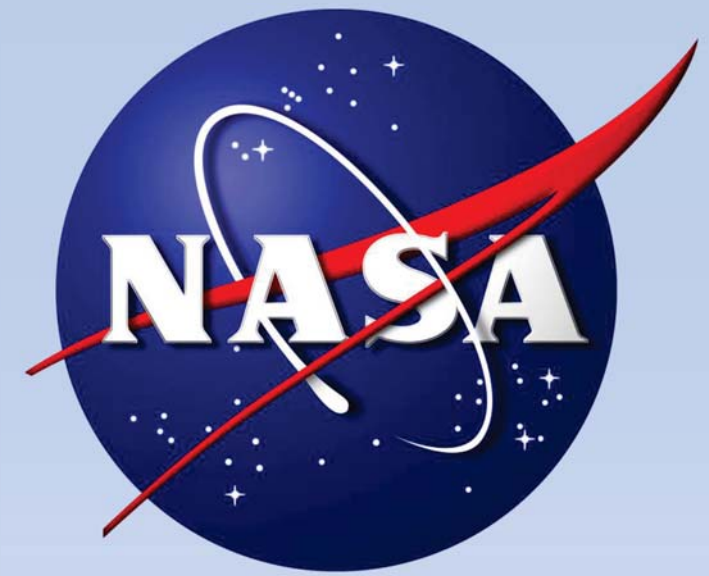
Panel ID	Patch Cure Method	Maximum Compressive Load (lbf)	Compressive Extension at Max Load (in)	Compressive Stress at Max Load (ksi)
G	None	51775	0.082	52.4
A	Precured	46608	0.071	47.4
B	Precured	49494	0.075	50.0
C	Cocure	38383	0.059	42.2
D	Cocure	38992	0.059	39.3
L	Cocure	34111	0.054	34.6
M	Partially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

Conclusions

- 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

Future Work

- 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

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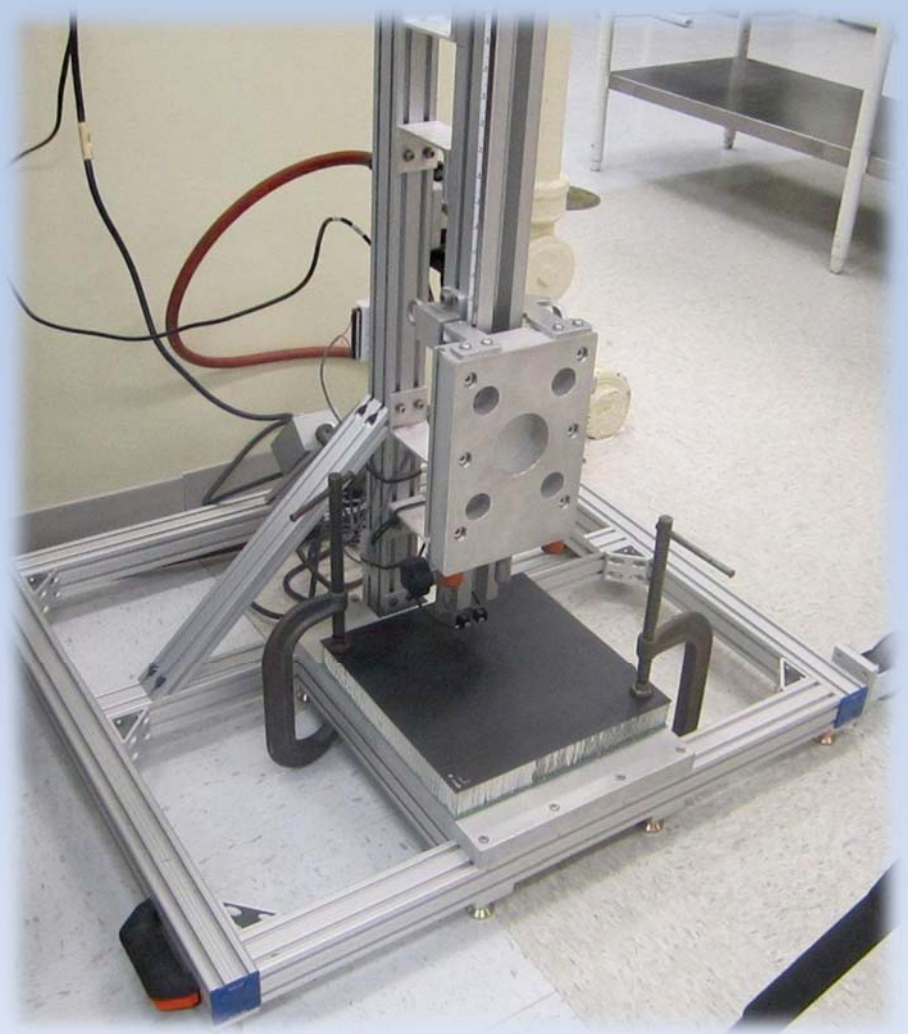
2. Douglas A. McCarville, et. al. (2013) “Manufacturing Overview of a 2.4 Meter Composite Cryotank.” *SAMPE Conference Proceedings*, Long Beach, CA, May 6-9, 2013.

3. Keller, R.L., Owen, W.S. “Process method to repair bismaleimide (BMI) composite structures.” (2004). *US Patent Number 6761783.* http://www.google.com/patents/US6761783

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



Composites for Exploration Project

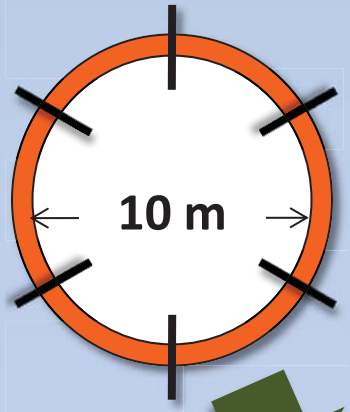
Vehicle	Heavy Lift	Atlas V	Delta IV
Dia	10 m	5.4 m	5.1 m
Area	~561 m^2	~311 m^2	~277 m^2

- 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

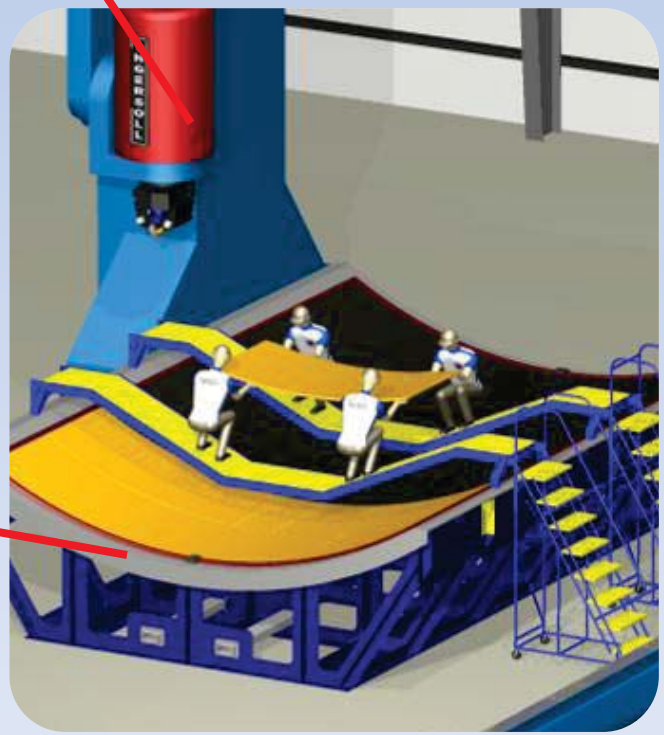
***out of autoclave**

1/6th – Arc Panel Fabrication



Automated Fiber Placement System

1/6th Tool Fabrication



Panels Not Completed

Panel E

Panel F