Composite Structures Repair Development at KSC

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Supporting Team

Panel Fabrication, Repair Work, Testing - KSC

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- *Terry Fan*

Agenda

- Background of Composites and Recent Agency Composite Projects
- Sandwich Panel Fabrication
- Repair Development and Testing

What is a Composite?

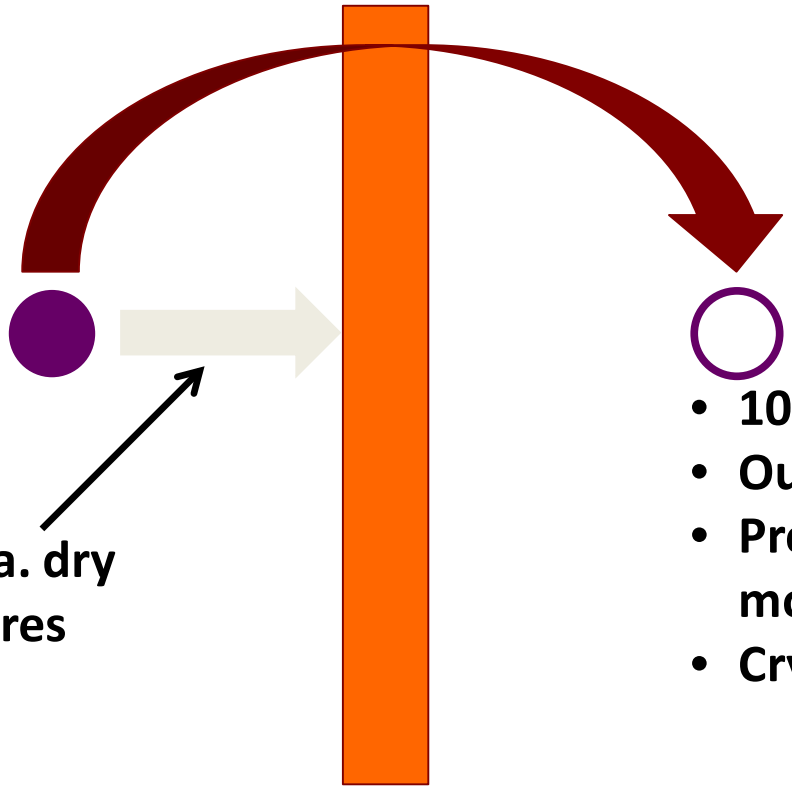
- Basic Definition: A material made up of two or more different materials which keep their individual properties
- Advanced Composite Materials: A fiber reinforced matrix
- Matrix
  - Polymer/Epoxy
  - Metal
  - Ceramic
- Reinforcement
  - Glass
  - Aramid (Kevlar)
  - Carbon
  - Ceramic
  - Natural

Strategy for Development

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

State of the art (SOA)

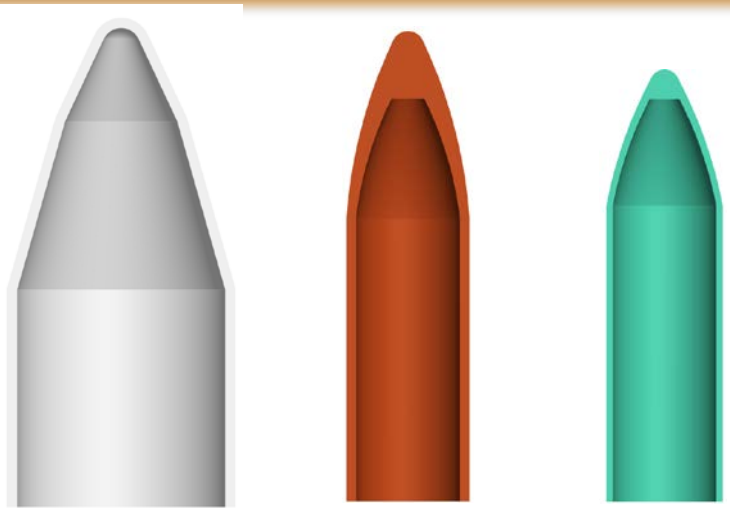
NASA's experience with composite primary structures for launch vehicles



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

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

Composites for Exploration



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**

Composite Cryotank Technologies and Demonstration

- Overall goal of the project is to achieve 30% weight savings and 25% cost savings of LH_2 composite cryotanks

http://gcd.larc.nasa.gov/projects/composite-cryogenic-propellant-tank/#.U3yoYfldWAg

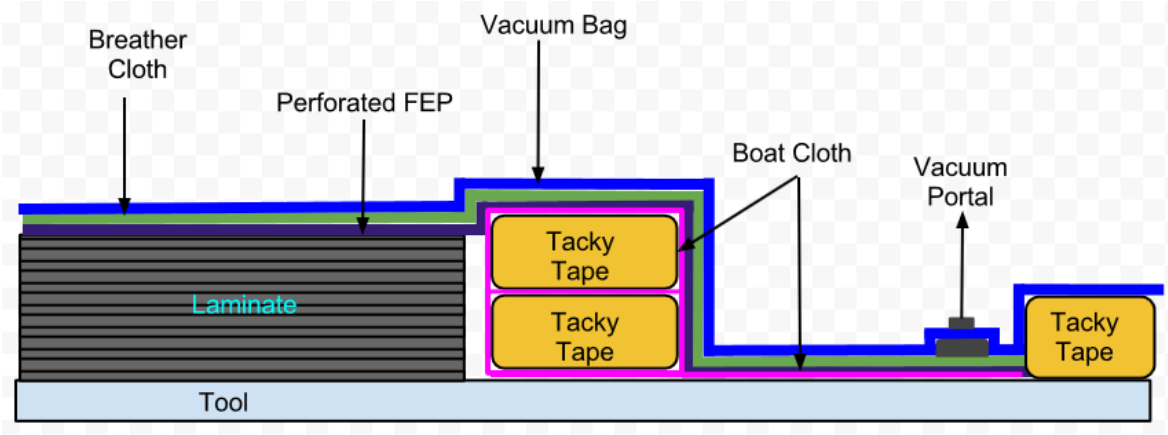
- 5.5-m tank was fabricated by Boeing and successfully tested at MSFC in 2014

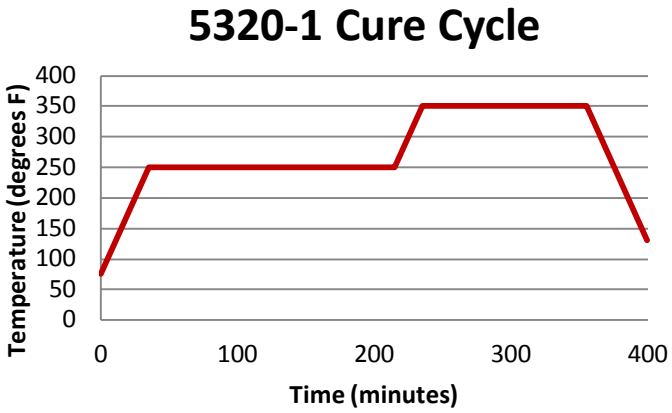
KSC Objectives

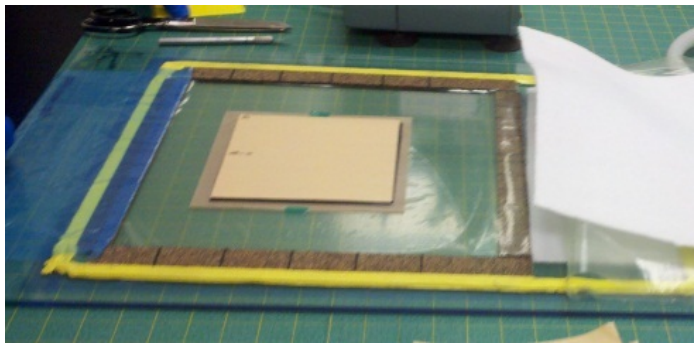
- Understand the properties of the composites
- Perform hands on repair work at KSC
- Investigate out of autoclave repair cure process

Composite Panel Fabrication

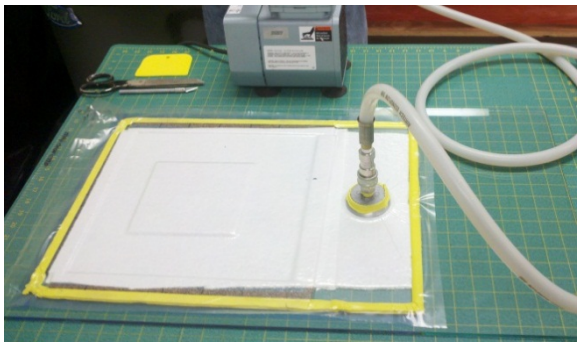
- HR40/5320-1 Prepreg Unitape
  - Out of Autoclave System
  - Hand Layup Method







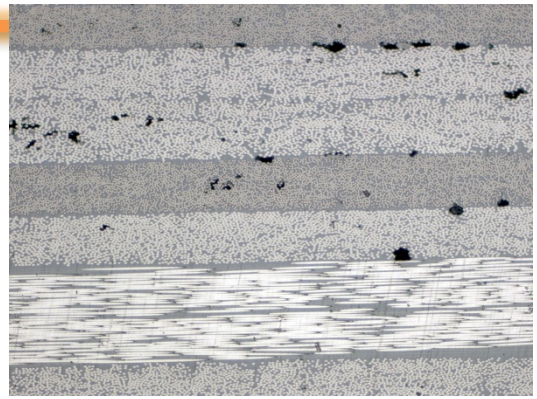
Vacuum Debulk of Composite Panel



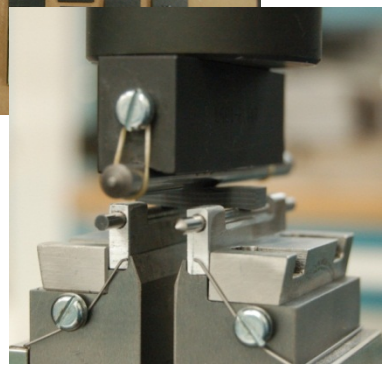
Oven Cure of Panel Under Vacuum

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



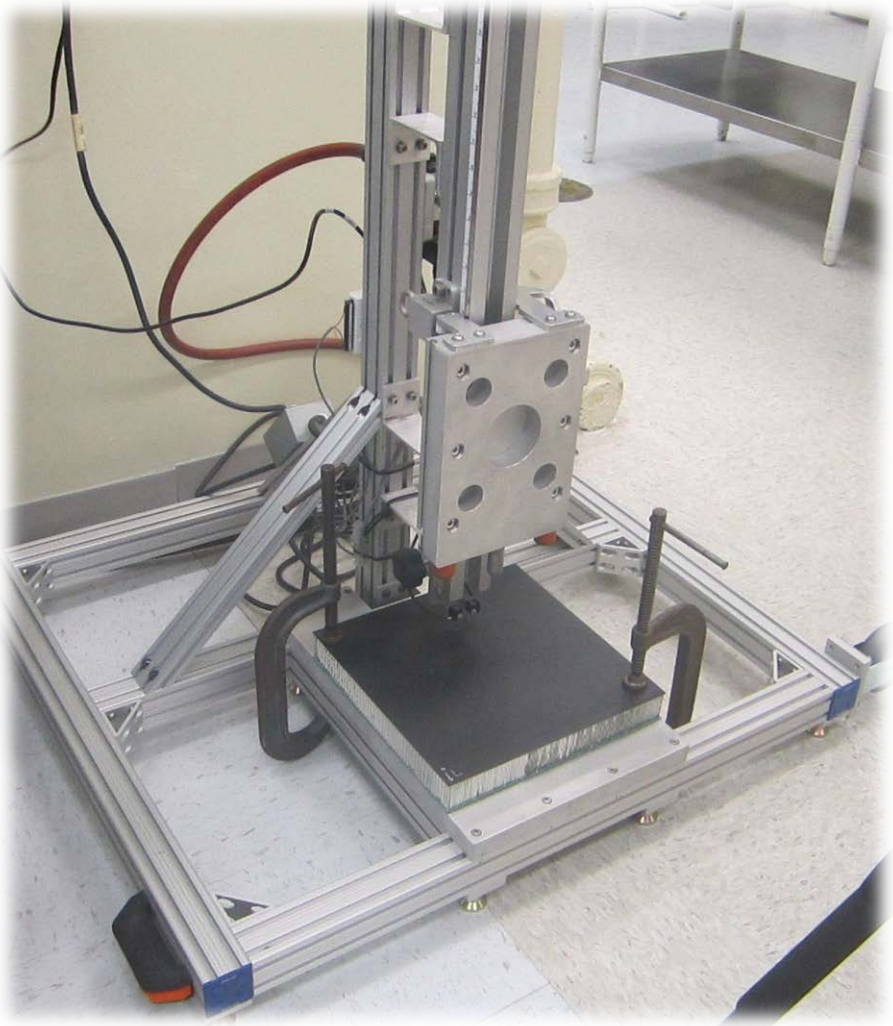
32-ply quasi isotropic panel, 100X



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

Impact Damage



Impacted Panel

Sandwich Panel Repair

Face Sheets

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

Core

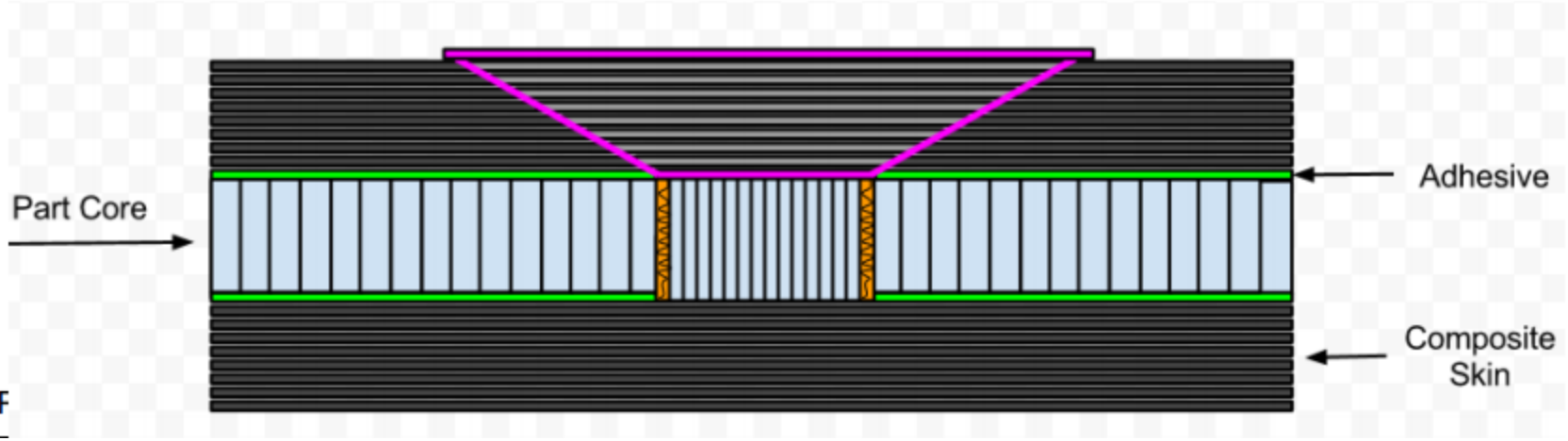
- 1.5” Aluminum Honeycomb
- FM-300 Film Adhesive

Repair Patch

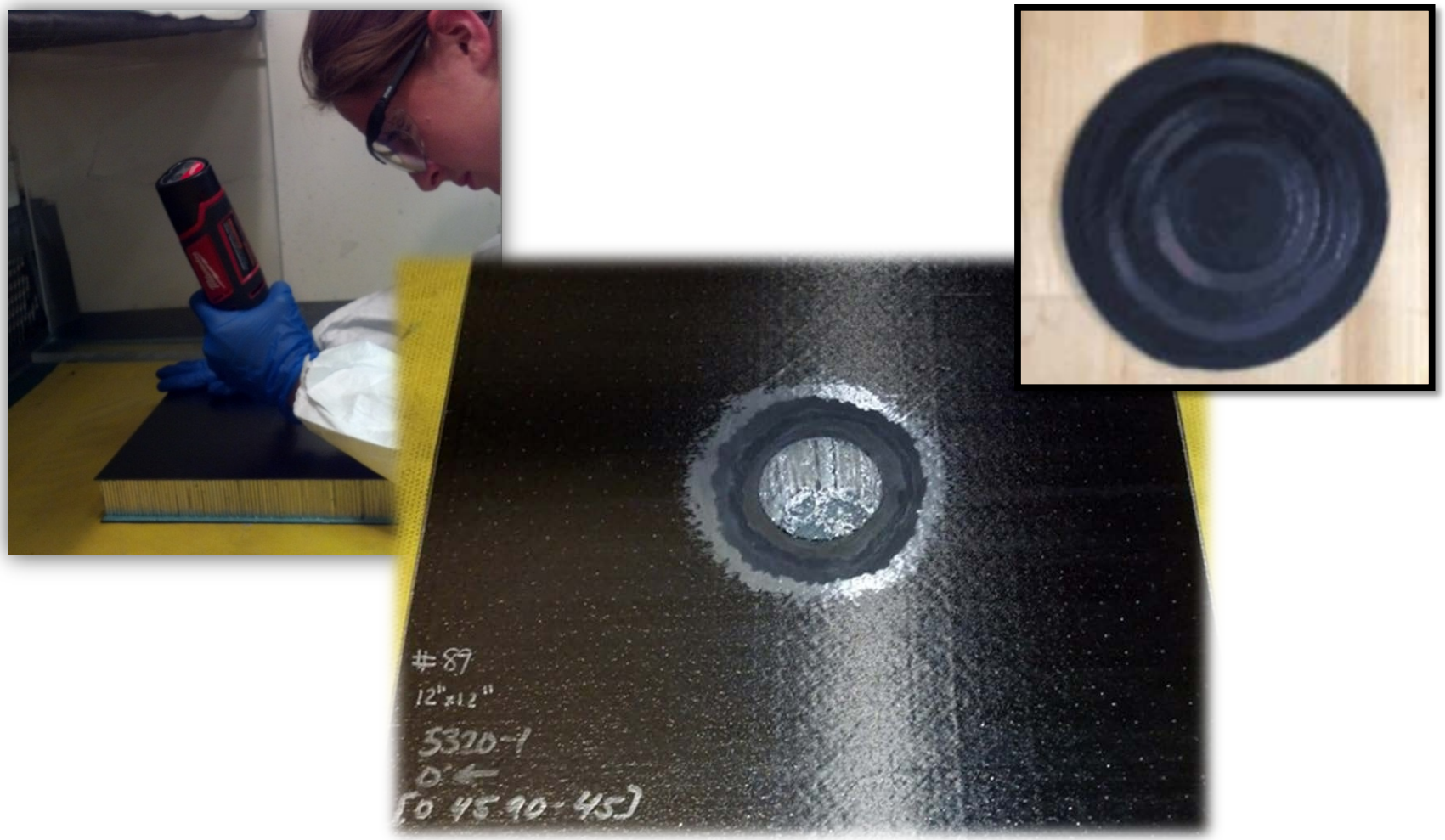
- HR40/5320-1 Unitape Prepreg
- FM-300 Film Adhesive

Core Plug

- 1.5” Aluminum Honeycomb
- Hysol MA 562 Foaming Adhesive



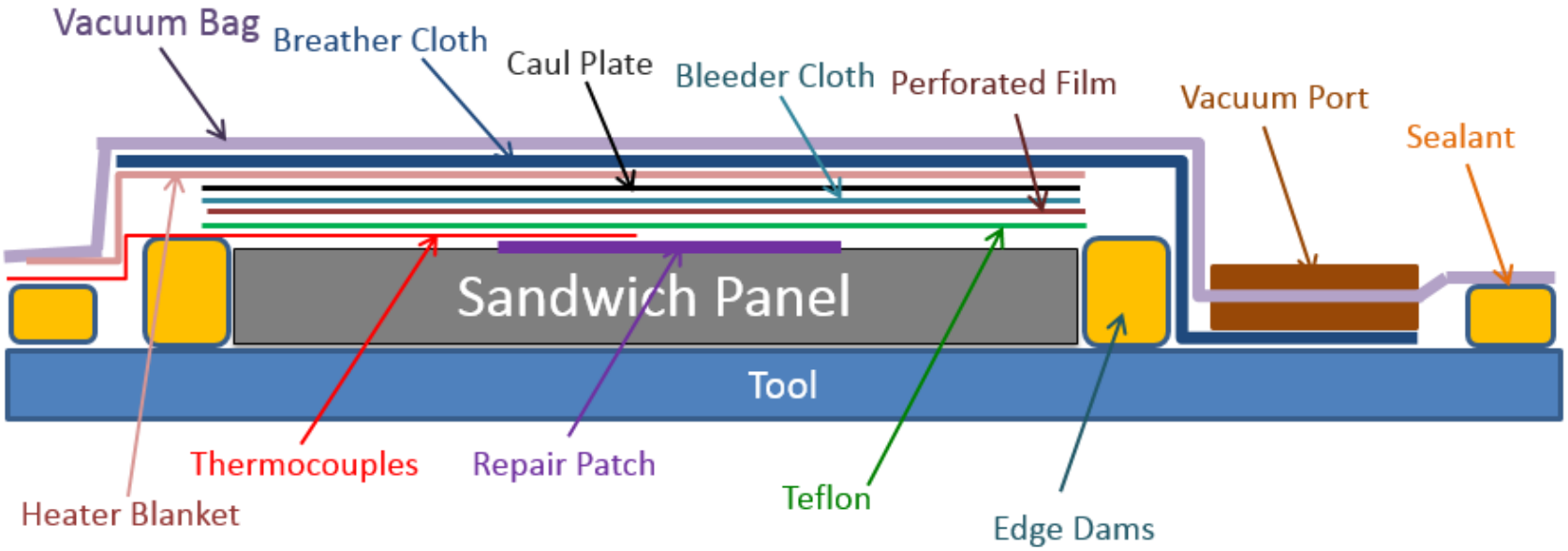
Facesheet Scarfing



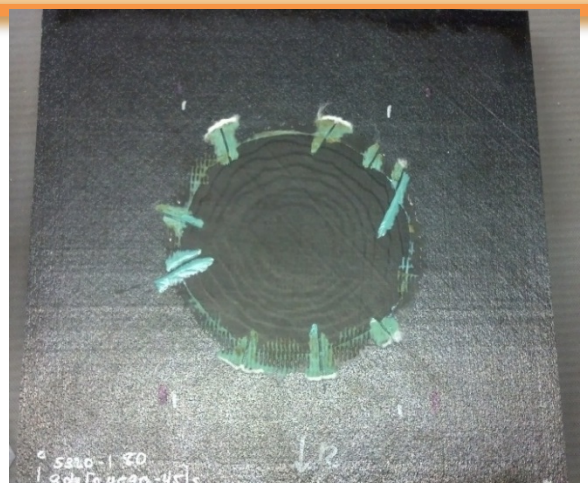
Patch Preparation Methods

- Method I: Pre-cured Patch
  - Patch was cured in an oven with the standard cure cycle
  - Patch was bonded to the part at 350^{o}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^{o}F for 3 hours and 350^{o}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^{o}F in an oven for 1 hour
    - Patch fully cured at 350^{o}F with the hot bonder for 2 hours on the part

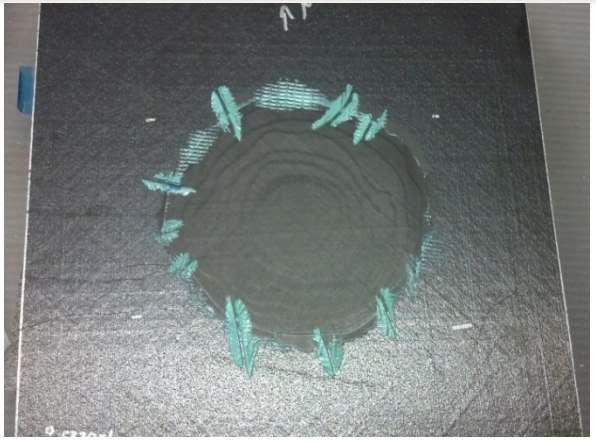
Patch Bonding



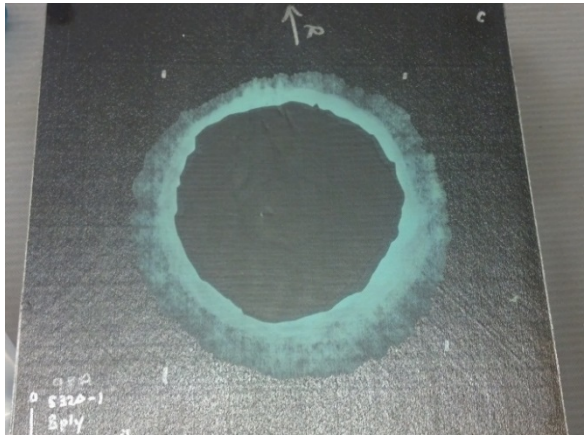
Repaired Panels



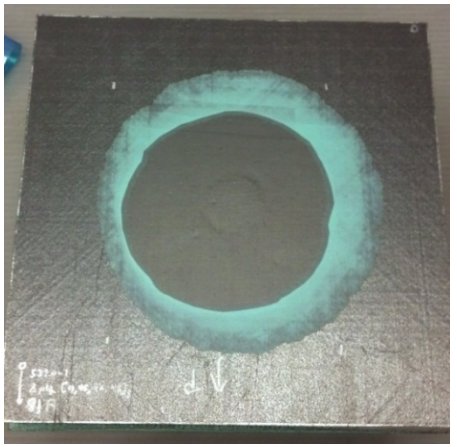
Panel A: Pre-cured Patch



Panel B: Pre-cured Patch



Panel C: Co-cured Patch



Panel D: Co-cured Patch

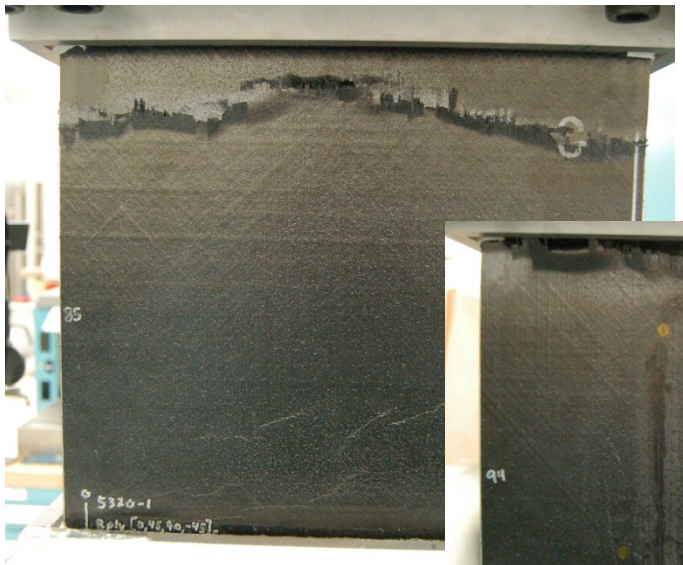
Edgewise Compression Testing

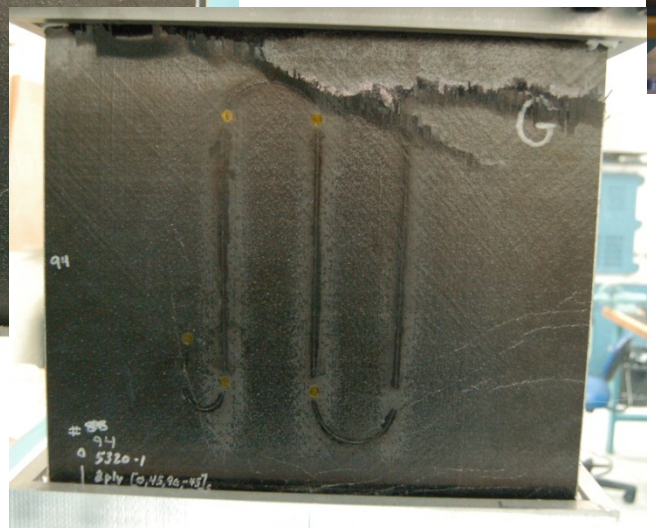
- ASTM C 364: Standard Test Method for Edgewise Compressive Strength of Sandwich Constructions
  - Assess the residual strength
- Panels potted into end caps to prevent brooming
- Edges wrapped to reduce stress

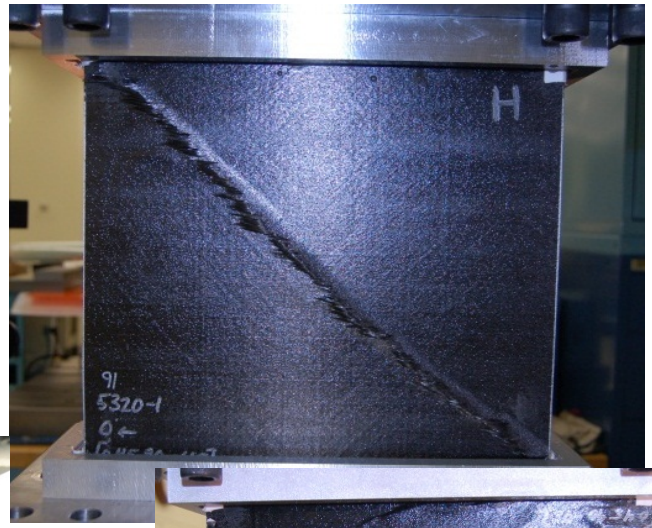
Edgewise Compression Testing

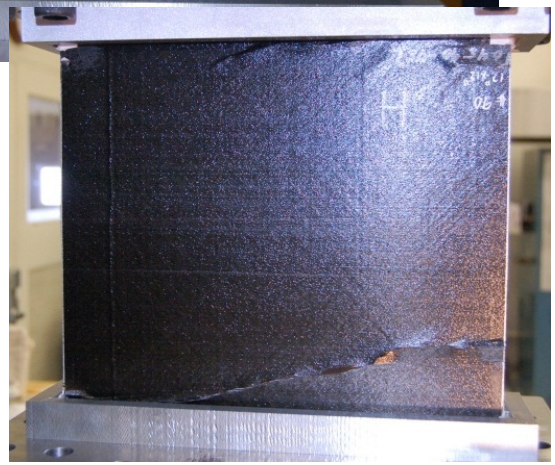
Control (no damage, no repair)

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		





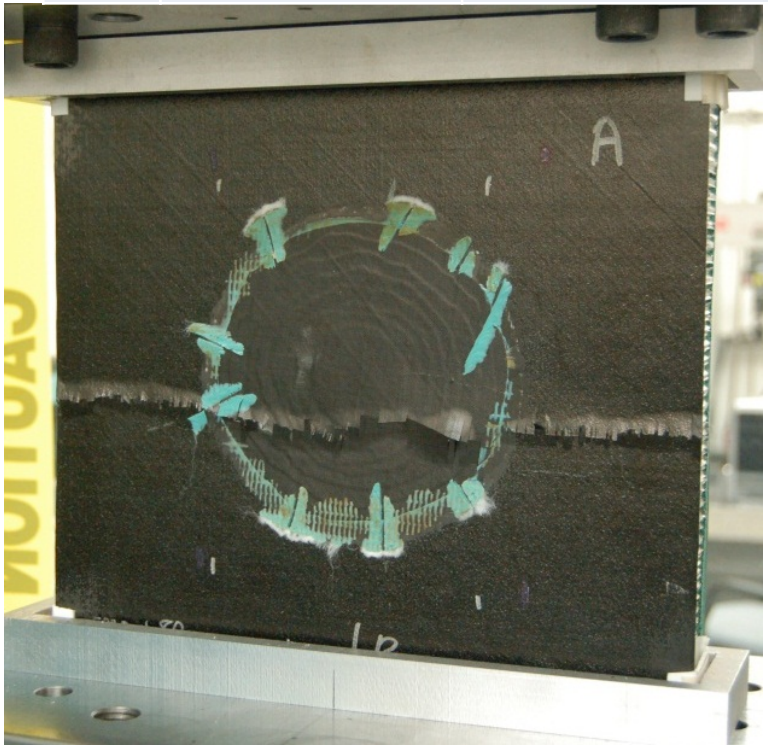


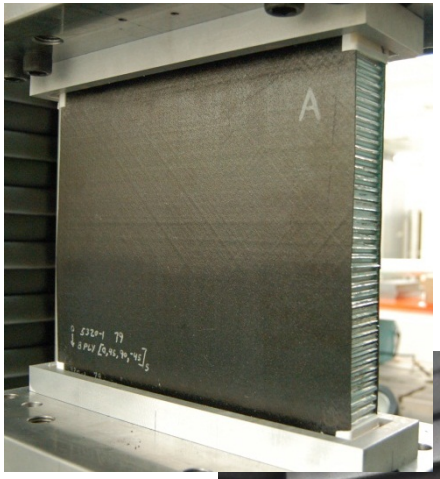


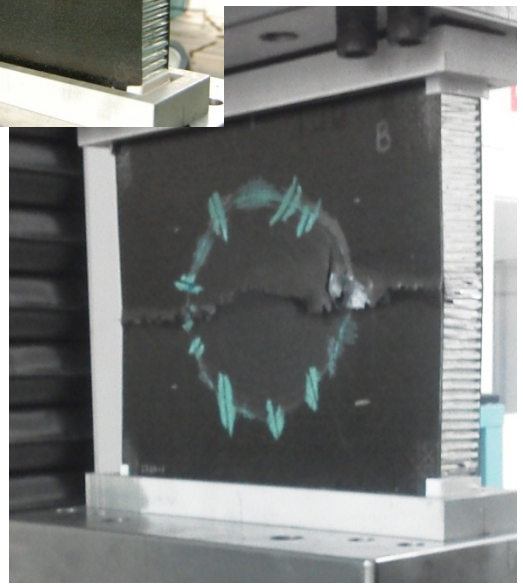
Edgewise Compression Testing

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



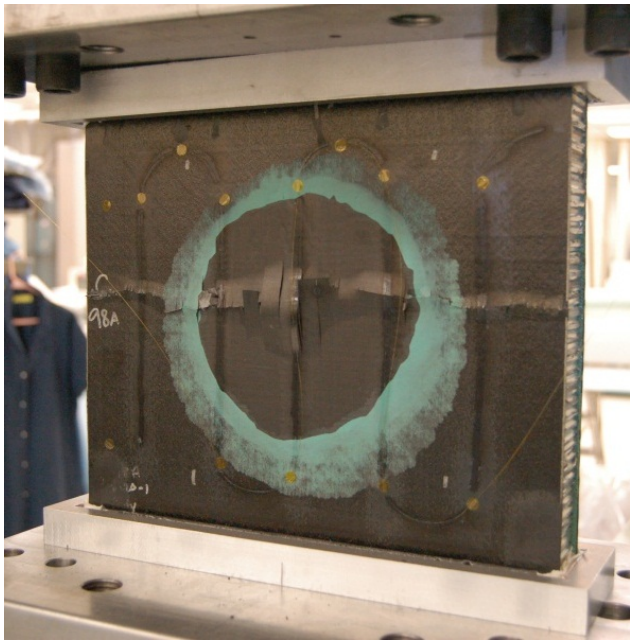


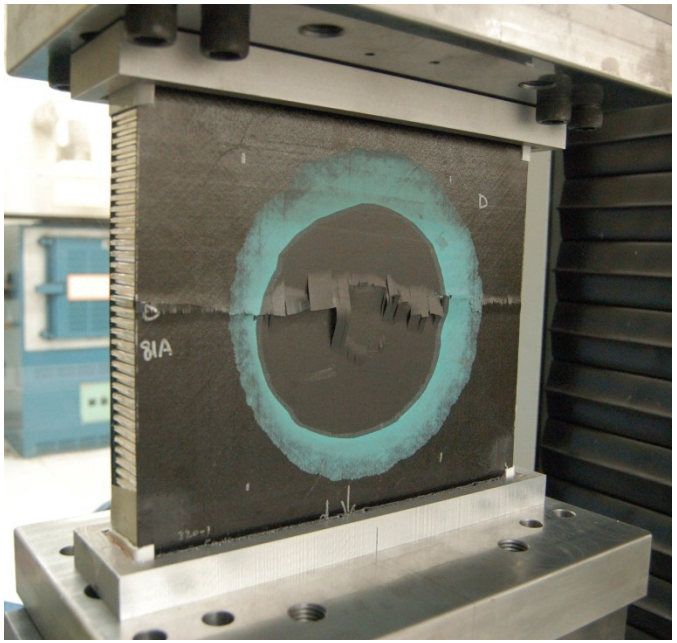


Edgewise Compression Testing

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





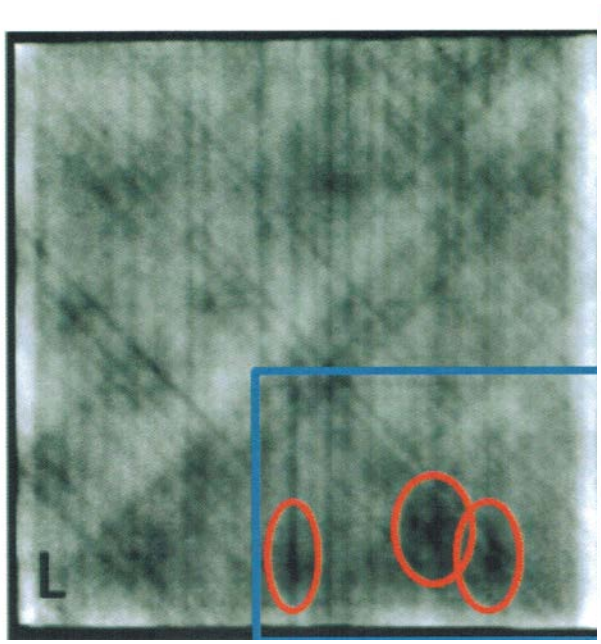
Partially Cured Patches

- 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

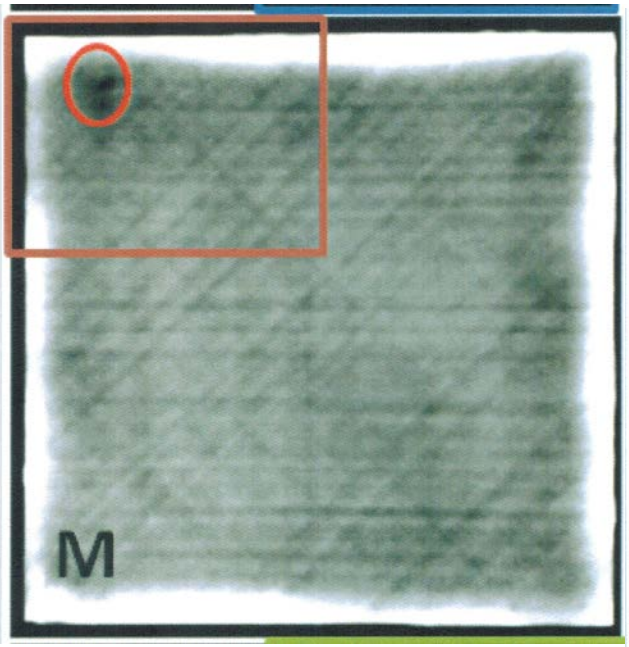
NDE during Repair Process

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

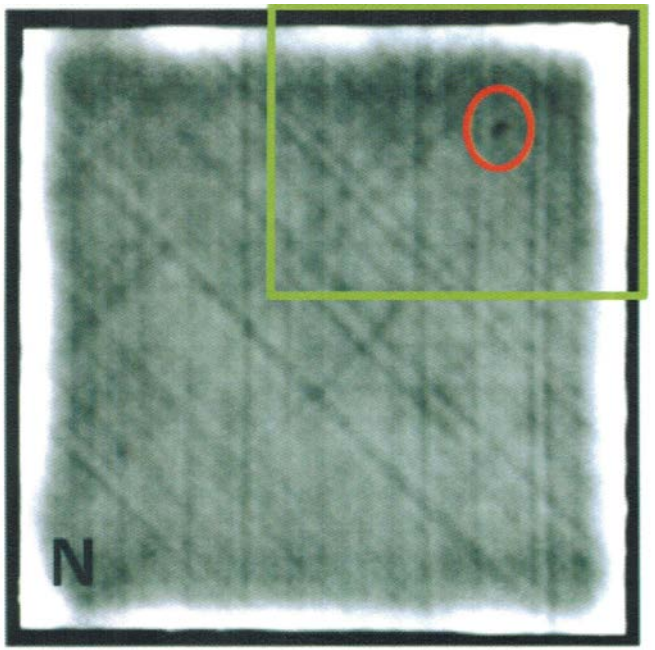
Initial IR Thermography Scan



Planned for Co-cured patch

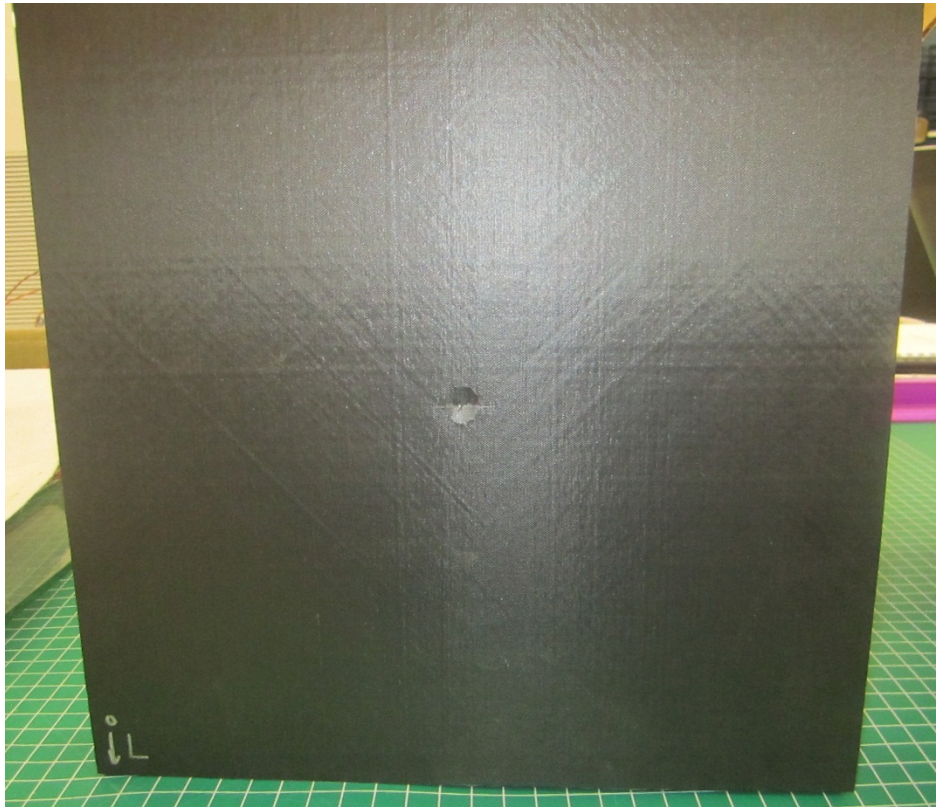


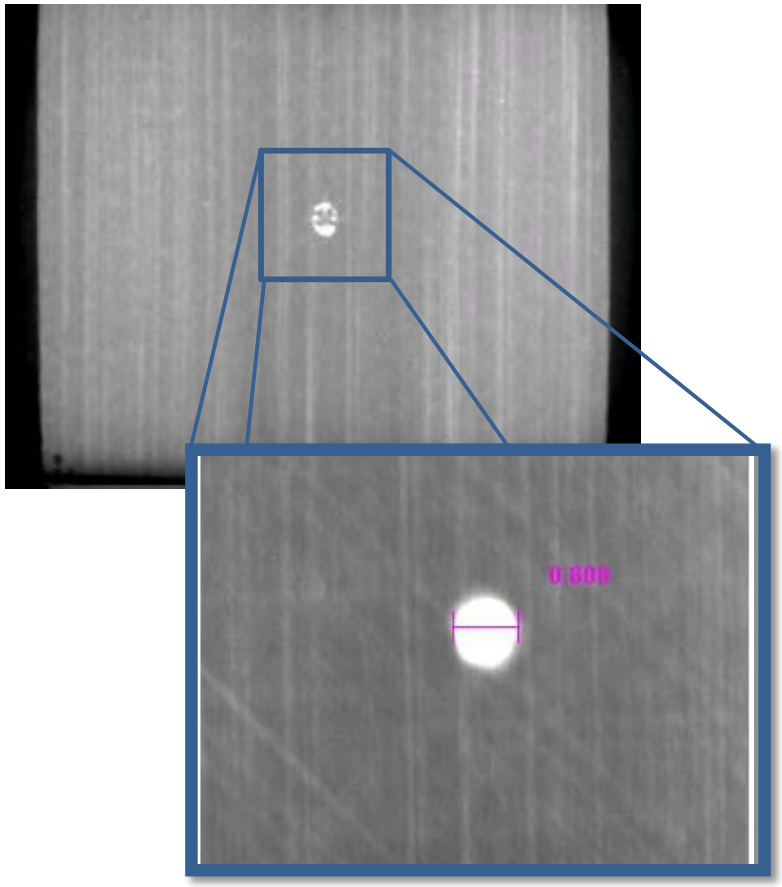
Planned for partially cured patch



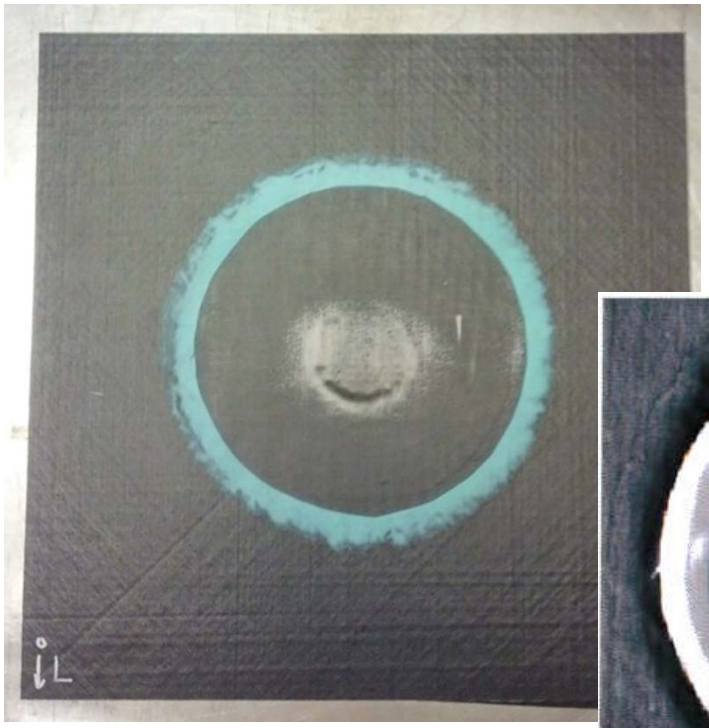
Planned for pre-cured patch

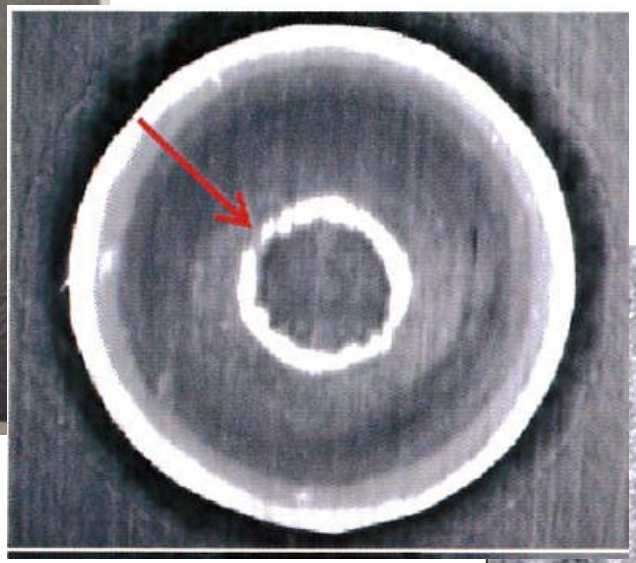
After Impact





After Repair – Co-cured Patch

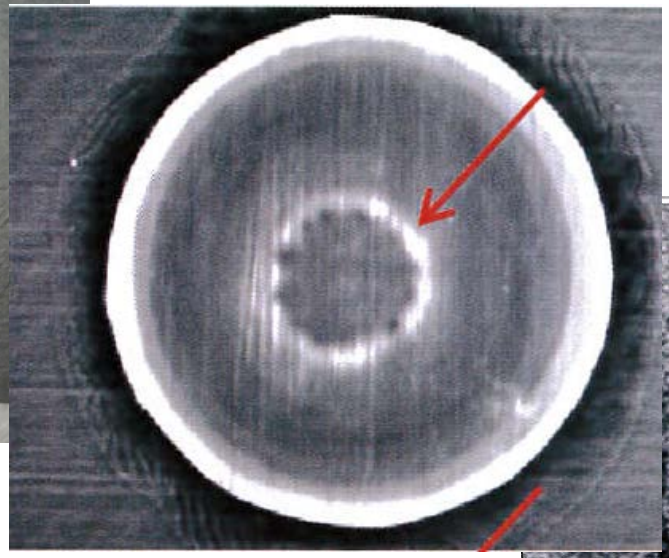




IR Thermography

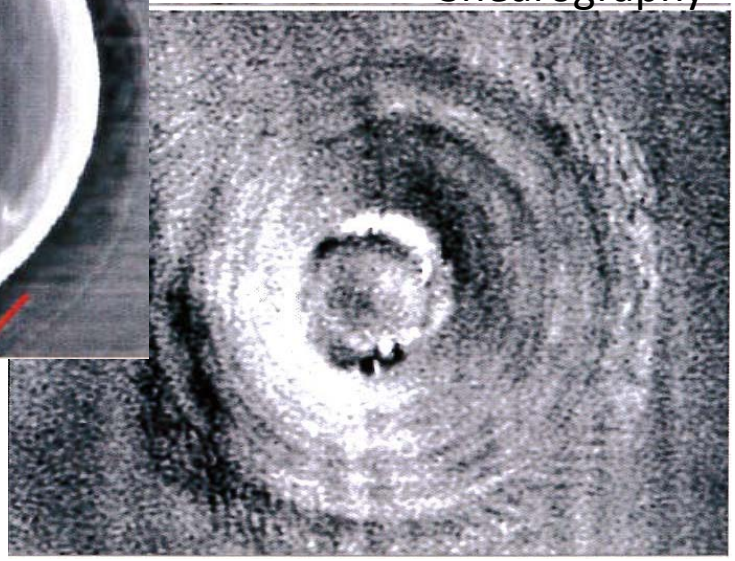
Shearography

After Repair – Partially Cured Patch

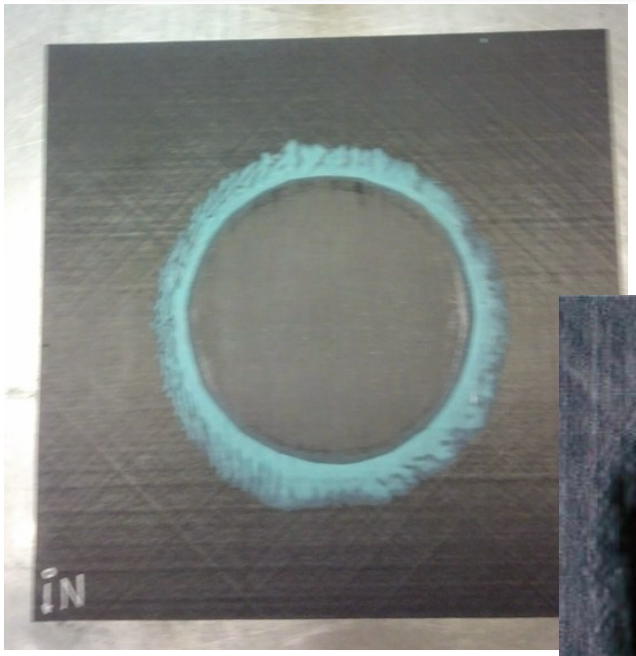


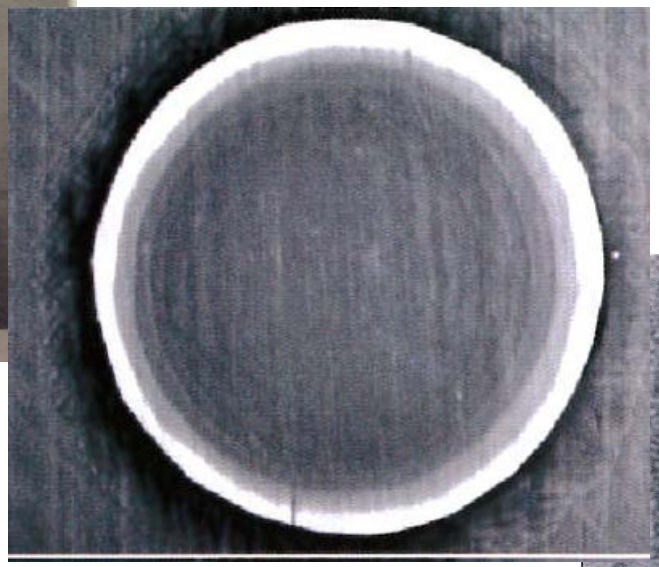
IR Thermography

Shearography



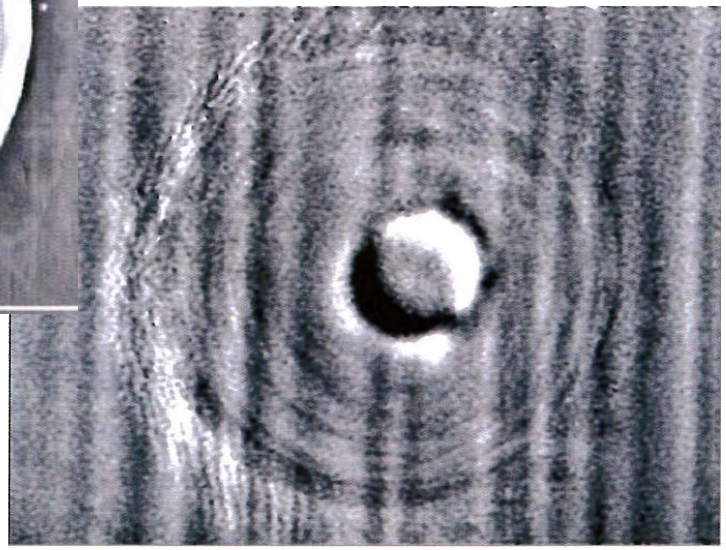
After Repair – Pre-cured Patch





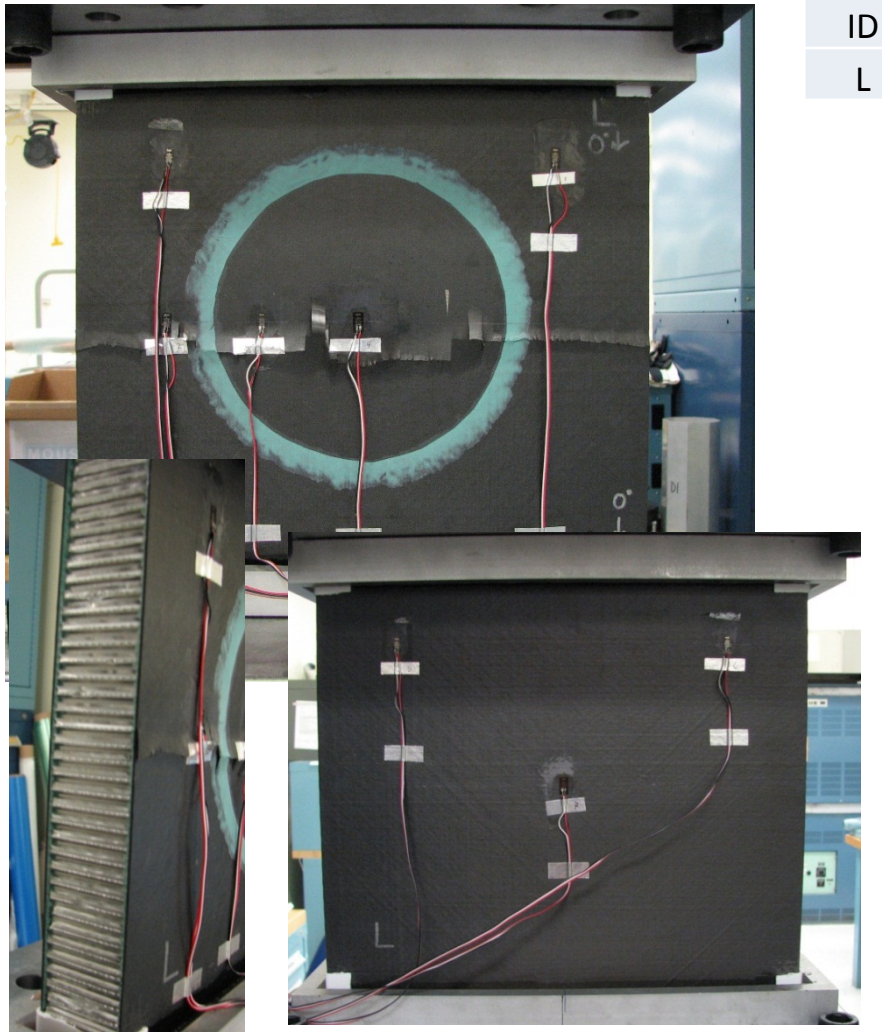
IR Thermography

Shearography

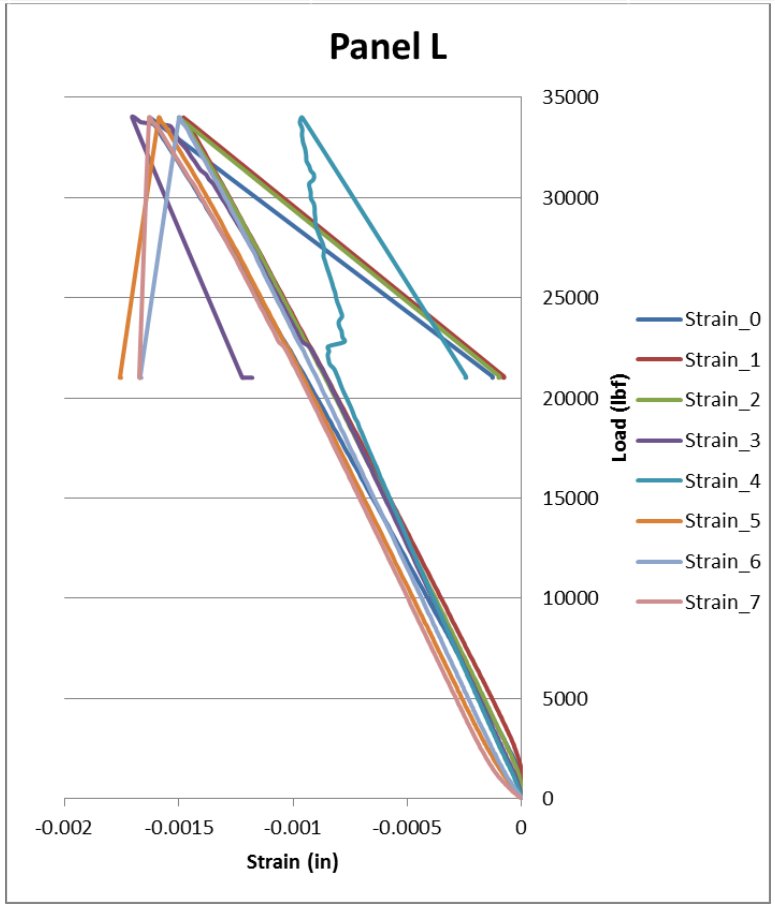


Edgewise Compression Testing

Co-cured Patch



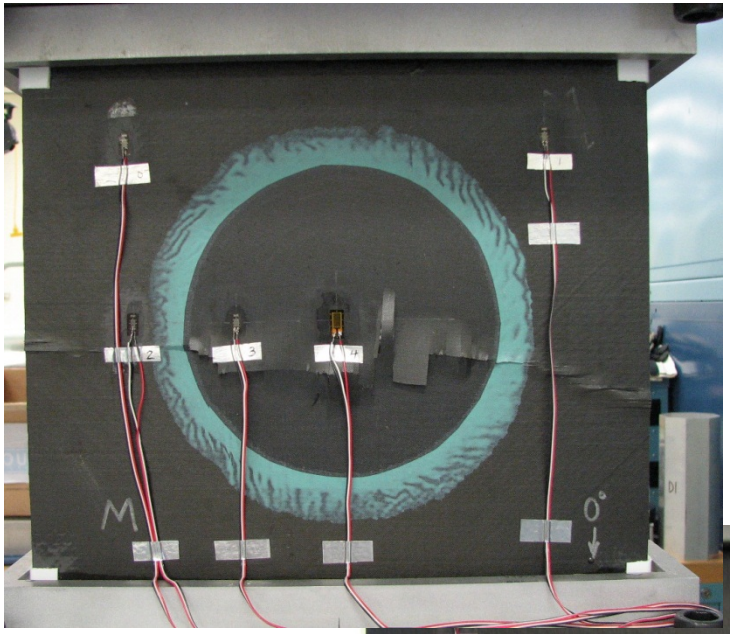
Panel ID	Maximum Compressive Load (lbf)	Compressive Extension at Max Load (in)	Compressive Stress at Max Load (ksi)
L	34111	0.054	34.6

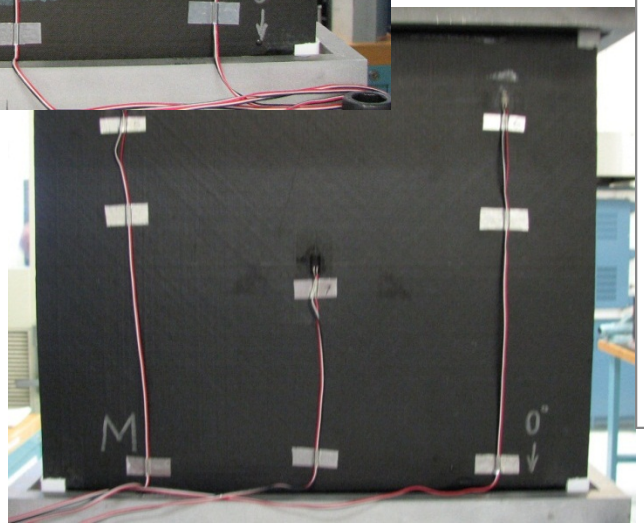


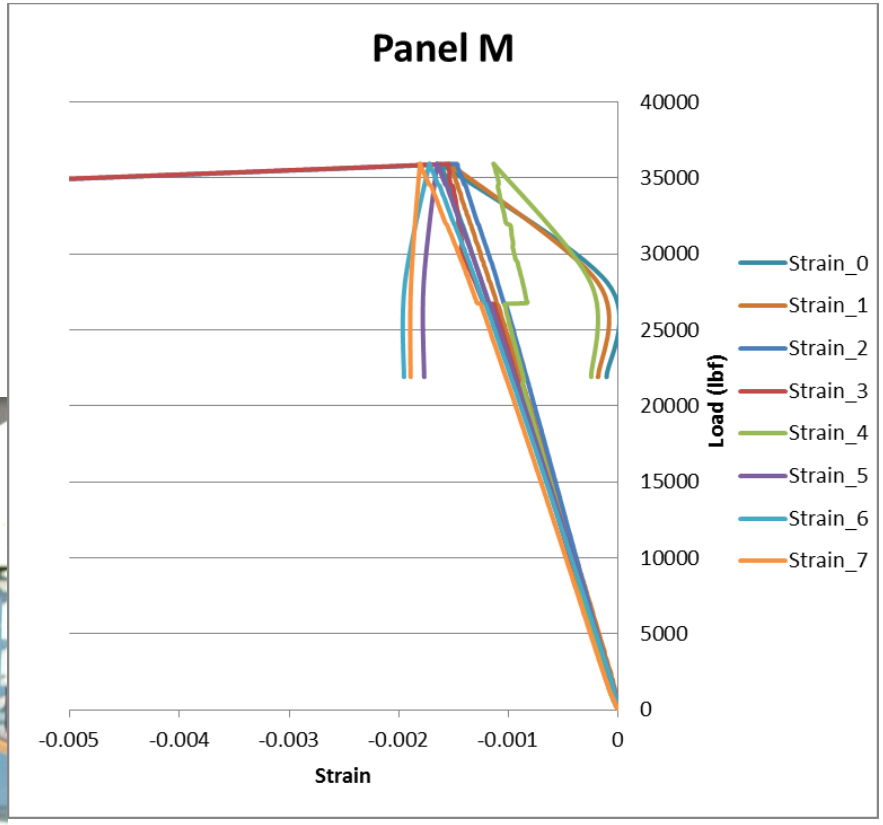
Edgewise Compression Testing

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



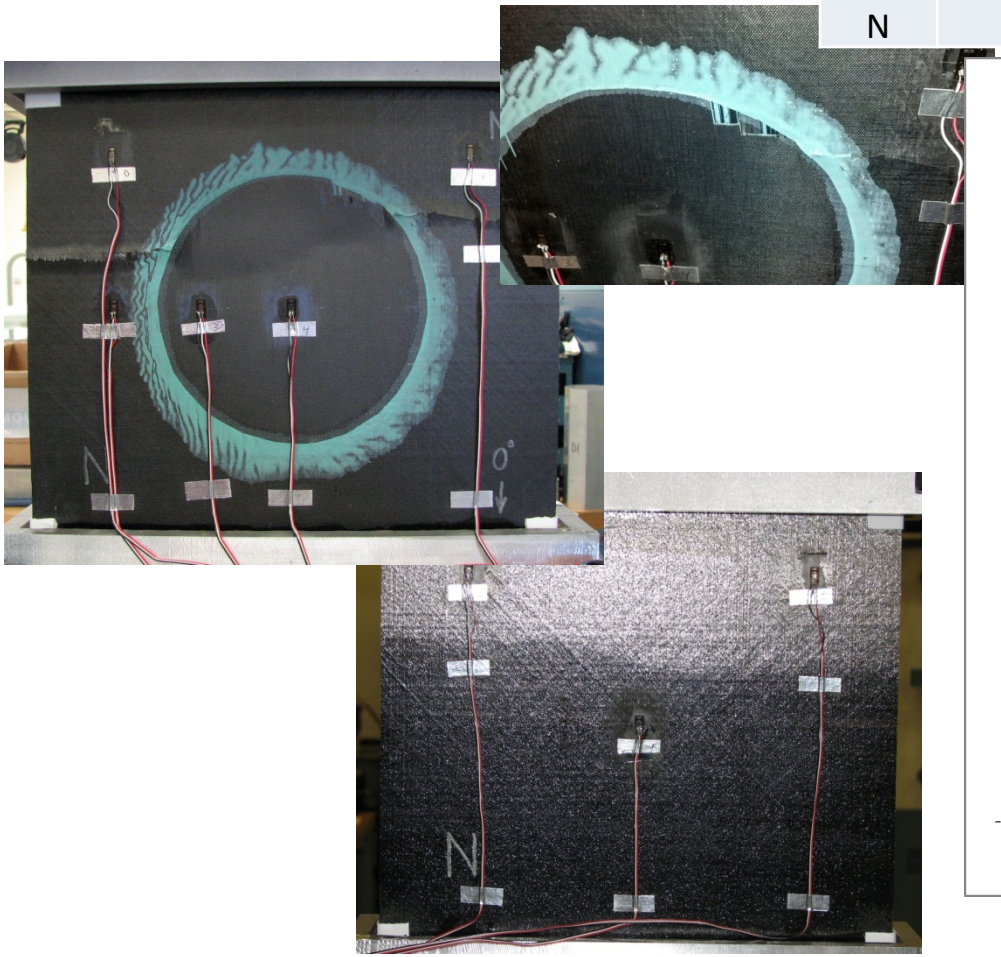


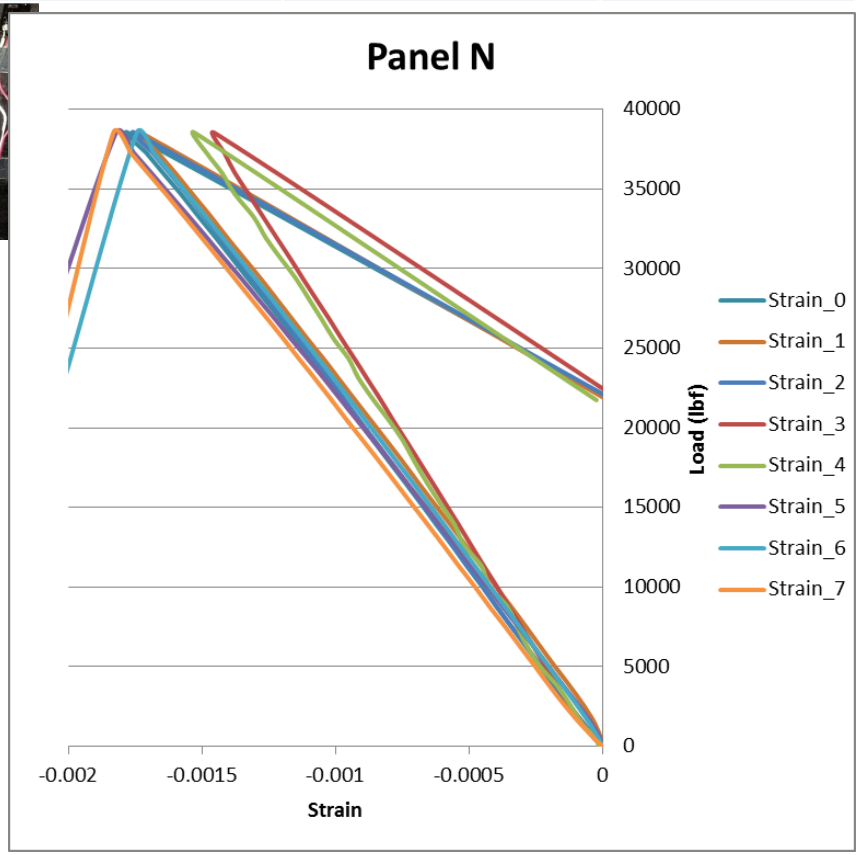


Edgewise Compression Testing

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 panels with damage, no repair
- 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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