Composite Structures Repair Development at KSC

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Supporting Team

Panel Fabrication, Repair Work, Testing - KSC
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• Brian Taylor

NDE – PAR Systems, Inc
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• Jeff Elston

Modeling and Analysis – GSFC
• Ken Segal
• Babak Farrokh
• 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

- 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

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Heavy Lift</th>
<th>Atlas V</th>
<th>Delta IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dia</td>
<td>10 m</td>
<td>5.4 m</td>
<td>5.1 m</td>
</tr>
<tr>
<td>Area</td>
<td>~561 m²</td>
<td>~311 m²</td>
<td>~277 m²</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CoEx Thrust</th>
<th>SOA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panels for 10-m-dia. barrels</td>
<td>No composites experience at this scale</td>
</tr>
<tr>
<td>Automated manufacturing</td>
<td>Limited to 7-m-dia. barrels</td>
</tr>
<tr>
<td>OoA* technologies</td>
<td>Maturing for aerospace quality</td>
</tr>
<tr>
<td>Design database</td>
<td>Not demonstrated for 10-m-dia. barrels</td>
</tr>
</tbody>
</table>

*out of autoclave
Overall goal of the project is to achieve 30% weight savings and 25% cost savings of LH$_2$ composite cryotanks.

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

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

![Diagram of Composite Panel Fabrication]

**5320-1 Cure Cycle**

- 0 100 200 300 400
- 0 50 100 150 200 250 300 350 400

Temperature (degrees F) vs. Time (minutes)

**Steps:**
- Breather Cloth
- Perforated FEP
- Vacuum Bag
- Boat Cloth
- Vacuum Portal
- Laminate
- Tool
- Tacky Tape

**Images:**
- 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°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
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

  - 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)

<table>
<thead>
<tr>
<th>Panel ID</th>
<th>Maximum Compressive Load (lbf)</th>
<th>Compressive Extension at Max Load (in)</th>
<th>Compressive Stress at Max Load (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>51775</td>
<td>0.082</td>
<td>52.4</td>
</tr>
<tr>
<td>H</td>
<td>Error During Data Collection</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Edgewise Compression Testing

Pre-cured Patch

<table>
<thead>
<tr>
<th>Panel ID</th>
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<th>Compressive Stress at Max Load (ksi)</th>
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<tbody>
<tr>
<td>A</td>
<td>46608</td>
<td>0.071</td>
<td>47.4</td>
</tr>
<tr>
<td>B</td>
<td>49494</td>
<td>0.075</td>
<td>50.0</td>
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</table>
## Edgewise Compression Testing

### Co-cured Patch

<table>
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<tr>
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<th>Compressive Stress at Max Load (ksi)</th>
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<tbody>
<tr>
<td>C</td>
<td>38383</td>
<td>0.059</td>
<td>42.2</td>
</tr>
<tr>
<td>D</td>
<td>38992</td>
<td>0.059</td>
<td>39.3</td>
</tr>
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</table>
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 – Partially Cured Patch

IR Thermography

Shearography
After Repair – Pre-cured Patch

IR Thermography

Shearography
Edgewise Compression Testing

Co-cured Patch

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<tr>
<td>L</td>
<td>34111</td>
<td>0.054</td>
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Edgewise Compression Testing

Partially Precured Patch

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<tr>
<td>M</td>
<td>36117</td>
<td>0.056</td>
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![Graph showing load vs. strain for Panel M](image)

[Image of partially precured patch panel]

[Image of partially precured patch panel with strain markers]
Edgewise Compression Testing

Precured Patch

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<tr>
<td>N</td>
<td>38934</td>
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![Graph of Panel N](image)
# Summary of Results

<table>
<thead>
<tr>
<th>Panel ID</th>
<th>Patch Cure Method</th>
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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
References


