Composite Structures Repair Development at KSC

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Supporting Team

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NDE – PAR Systems, Inc
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• 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
NASA’s experience with composite primary structures for launch vehicles:
- 5-m-dia. dry structures

Leapfrogging the SOA puts NASA in a leadership position to drive technology development:
- 10-m-dia. structures
- Out-of-autoclave processing
- Pressurized habitation modules
- Cryotanks
**Composites for Exploration**

**Vehicle**

<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>

* 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>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*
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

• 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

**5320-1 Cure Cycle**

- 0 100 200 300 400
- 0 50 100 150 200 250 300 350 400
- Temperature (degrees F)
- Time (minutes)

**Vacuum Debulk of Composite 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
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

![Diagram of sandwich panel repair](image-url)
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

Diagram showing the components of a patch bonding process:
- Vacuum Bag
- Breather Cloth
- Caul Plate
- Bleeder Cloth
- Perforated Film
- Vacuum Port
- Sealant
- Thermocouples
- Repair Patch
- Teflon
- Edge Dams
- Tool
- Sandwich Panel
- Heater Blanket
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>

![Panel G](image1.png)

![Panel H](image2.png)
# Edgewise Compression Testing

## Pre-cured Patch

<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>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>
</tr>
</tbody>
</table>
## Edgewise Compression Testing

### Co-cured Patch

<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>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>
</tbody>
</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 Repair – Co-cured Patch

- IR Thermography
- Shearography

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

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<tr>
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<tbody>
<tr>
<td>L</td>
<td>34111</td>
<td>0.054</td>
<td>34.6</td>
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</table>

![Graph showing load vs. strain for Panel L]
# Edgewise Compression Testing

**Partially Precured Patch**

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>M</td>
<td>36117</td>
<td>0.056</td>
<td>36.6</td>
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![Graph showing strain vs load for Panel M]
Edgewise Compression Testing

Precured Patch

<table>
<thead>
<tr>
<th>Panel ID</th>
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<tr>
<td>N</td>
<td>38934</td>
<td>0.059</td>
<td>39.5</td>
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</table>

Panel N

- Strain_0
- Strain_1
- Strain_2
- Strain_3
- Strain_4
- Strain_5
- Strain_6
- Strain_7

Load (lbf) vs. Strain

Strain range from -0.002 to 0
# Summary of Results

<table>
<thead>
<tr>
<th>Panel ID</th>
<th>Patch Cure Method</th>
<th>Maximum Compressive Load (lbf)</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
Questions?

