Recent Advances in Near-Net-Shape Fabrication of Al-Li Alloy 2195 for Launch Vehicles

John Wagner, Marcia Domack and Eric Hoffman
NASA Langley Research Center
Hampton, VA

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Recent Advances in Near-Net-Shape Fabrication of Al-Li Alloy 2195 for Launch Vehicles

Outline

• Background on Al-Li alloy and Near-Net-Shape Fabrication Technologies for the Launch Vehicle industry

• Ares I Roll Forged Adapter Rings

• Exploration Technology Development Program Spun Formed Domes

• Future Opportunities for 2195 Near-Net-Shape Components

• Remaining Challenges
Near-Net-Shape Manufacturing of Al & Al-Li Alloys For Launch Vehicle Structures

- **Shear Forming**
  - Seamless Cryotank Section
  - Steel Cylinder

- **Roll Forging**
  - Adapter Rings

- **Friction Stir Welding**
  - Butt & Lap Joints

- **Integrally Stiffened Extrusion**
  - Cryotank Barrel Panels

**BENEFITS**

- Reduced Material Scrap Rate
- Lower Cost, Enhanced Performance
- Increased Reliability
- Reduced Part Count
- Reduced Assembly Time
Advanced Aluminum Alloys Technologies for Space Transportation Systems

Benefits of Al-Li Alloys
- Lower Density
- Higher Strength
- Higher Modulus
- Good Cryogenic Toughness
- Good Formability & Weldability

Current Applications
- Space Shuttle External Tank and Intertank Structures
- F-16 Bulkheads
- Airbus A380 primary structure

John.A.Wagner@nasa.gov
Cryogenic Tank Technology Program

- Dome Cap
- Adapter Ring
- Barrel Section

- Joint NASA LaRC-MSFC-Lockheed Martin
- Applies Al-Li Near Net Forming Methods Developed Through LaRC Programs
- Longitudinal & Circumferential Friction Stirwelds at MSFC
- Concept Demonstration Tank
- Constructed from Al-Li alloy 2195

Vendors
- McCook Metals Co.- 2195 Al-Li Alloy
- Zeppelin - Spun Formed Domes
- Wyman Gordon - Extruded Barrel Section Panels
- Ladish Corp. - Roll Forged Adapter Rings

John.A.Wagner@nasa.gov
PROCESS OPTIMIZATION FOR THIN-WALLED 2195 ALUMINUM SHEAR FORMED CYLINDERS

Shear Forming Process

2195 Shear Formed Cylinder (14' Diameter; 0.18" Wall Thickness)

Through-Thickness Microstructures of 14' Diameter Al-Li 2195 Shear Formed Cylinders

Tensile Properties of 14’ Diameter 2195-T8 Shear Formed Cylinder

Process Potential
- Seamless cylinders up to 22 foot diameter
- Reduce/eliminate longitudinal joints/welds

2195 SFC I
- tf=0.15 inches

2195 SFC II
- tf=0.18 inches

Process parameter optimization yields refined, symmetrical microstructure
Space Shuttle Super Lightweight External Tank

- Space Shuttle system redesigned to support space station launch requirement of 51.6° angle of inclination

- SLWT program requirement was an 8,000 lb. system weight reduction
  - System redesigned: T-stiffened → orthogrid
  - Material Replacement: Al 2219 → Al-Li 2195

- Program initiated in 1994; First SLWT flight was STS-91, June 1998
Super Lightweight Tank Program
Materials Testing and Characterization Program

Biaxial Test Stand

Alloy Development
- Composition
- Processing
- Aging
- Plate, extrusions, forgings

Mechanical Property Evaluation
- Tensile/Compression
- Precision Modulus
- Fracture Toughness
- Biaxial Tension
- Amsler Shear

Metallurgical Characterization
- Metallography
- Chemical Analysis
- Microhardness
- Fractography
- Differential Scanning Calorimetry

Yield Load Locus for 2219 & Al-Li 2195

John.A.Wagner@nasa.gov
Ares I Configuration
Crew Launch Vehicle (CLV)

Orion
• Crew Exploration Vehicle (CEV)

Upperstage
• Liquid Oxygen/Liquid Hydrogen stage
• 5.5-m diameter
• Aluminum-Lithium (Al-Li) structures

First Stage
• Derived from current Shuttle Reusable Solid Rocket Motor/Booster (RSRM/B)
Roll Forged Al-Li 2195 Process Development Rings

Ingot

Billet

Back Extrusion

Ring Roller

Ring Preforms

John.A.Wagner@nasa.gov
Near-Net-Shape Manufacturing of Al-Li Alloy 2195 for Launch Vehicles

### Target Properties

<table>
<thead>
<tr>
<th>Temper</th>
<th>Thickness (in)</th>
<th>Orient.</th>
<th>UTS, Min. (ksi)</th>
<th>YS, Min. (ksi)</th>
<th>% el, Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>T8A3</td>
<td>0.5 to 2.0 in.</td>
<td>Circ. / Axial</td>
<td>78</td>
<td>73</td>
<td>5</td>
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<tr>
<td></td>
<td>Radial</td>
<td></td>
<td>70</td>
<td>63</td>
<td>2</td>
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</tbody>
</table>

CLV Upper Stage Manufacturing Requirements Document

### Demonstrated Properties

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<tr>
<th>Temper / Orientation</th>
<th>Temp.</th>
<th>Thickness (in)</th>
<th>UTS (ksi)</th>
<th>YS (ksi)</th>
<th>% el</th>
</tr>
</thead>
<tbody>
<tr>
<td>T8 / Axial</td>
<td>RT</td>
<td>1.0 in.</td>
<td>83.0</td>
<td>75.0</td>
<td>10.1</td>
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<tr>
<td></td>
<td></td>
<td>2.0 in.</td>
<td>82.8</td>
<td>75.6</td>
<td>9.1</td>
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<tr>
<td></td>
<td>LN2</td>
<td>1.0 in.</td>
<td>98.4</td>
<td>88.9</td>
<td>7.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0 in.</td>
<td>95.6</td>
<td>84.3</td>
<td>10.6</td>
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</tbody>
</table>

Average of Multiple Roll Forgings
ARES I Cryogenic Tank Single-Piece Y-ring Adapter Manufacturing Plan

Al-Li 2195 ingot processing to rough pre-form

Roll forge to target diameter
Rectangular cross section

Contour machine
Post-fabrication processing

Final Machine

Y-ring Cross Section

Roll Forged Ring Cross Section

John.A.Wagner@nasa.gov
Cryogenic Tank Dome Manufacturing by Gore Assembly
Multi-piece; Welded Construction

1. Ingot
2. Plate
3. Mandrel
4. Gore
5. Dome Gore Panel
6. Dome Gores
7. Welded Gore Assy. Complete Dome
8. Dome Cap
9. Tank Barrel
10. Dome/Barrel Y-ring
11. Friction Stir Welded MFG Article

John.A.Wagner@nasa.gov
ARES I Cryogenic Tank Single-Piece Dome Manufacturing Plan

Friction Stir Welded Al-Li 2195 Plate

2195 commercial plate limits
spin forming blank size

FSW multi-piece blank

FSW is mature technology for 2195

Spin Forming

Post-fabrication Processing

2195 spun formed dome
Sub-scale
FSW blank

Al-Li Alloy 2195
14-foot diameter
Single piece blank
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**First Stage**
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**Frustum**
Launch Vehicle Frustum Concept and Ladish Produced Forward Exit Cone

Typical Frustum Structure

Forward Exit Cone

D6AC Steel
Potential Applications to Orion Crew Exploration Vehicle (CEV)

- Rings
- Cylinders
- Conical Shapes
- Tanks
Recent Advances in Near-Net-Shape Fabrication of Al-Li Alloy 2195 for Launch Vehicles

Remaining Challenges

Recent applications in launch vehicles use 2195 processed to Super Lightweight Tank specifications. Potential benefits exist by tailoring heat treatment and other processing parameters to the application.

Assess the potential benefits and advocate application of Al-Li near-net-shape technologies for other launch vehicle structural components.

Work with manufacturing and material producers to optimize Al-Li ingot shape and size for enhanced near-net-shape processing.

Examine time dependent properties of 2195 critical for reusable applications.