Manufacturing Challenges Implementing Material Changes for the Super Light Weight External Tank

A Welding Process Perspective

Kirby Lawless and Chip Jones
Super Lightweight External Tank

Al-Li Weight Savings

1791 Oxygen Tank
929 Intertank
5283 Hydrogen Tank

8003 Pounds Total
Liquid Hydrogen Tank

- Substitute Al 2195 for Al 2219
- Redesign to Orthogrid Waffle
- Optimize TPS Application
- Weight Savings - 4,200 lbs

Super Lightweight Tank
Delivers 7,500 lbs of Additional Payload

- Substitute Al 2090 for Al 2024 and Al 7075
- Machine TPS After Application
- Weight Savings - 750 lbs

Intertank

- Substitute Al 2195 for Al 2219
- Resize Panel Thickness
- Optimize TPS Application
- Weight Savings - 1,620 lbs

Liquid Oxygen Tank

- Substitute Al 2195 for Al 2219
- Resize Panel Thickness
- Optimize TPS Application
- Weight Savings - 1,620 lbs

Legend:
- Yellow = Al Li 2090, 2195
- Gray = Other Redesigned Parts
- Black = No Change
Super Lightweight Tank

- One-Half Mile of Weld Joints per Tank
  - Thickness ranges from 0.140” to 0.991”
  - Plate, Extrusion, Forging Product Forms
- Initial Automated 3-Pass Weld Process
  - Four basic geometries:
    - Dome Gores, Ojives
    - Longitudinal
    - Circumferential
    - Circular Caps and Fittings
  - Repair Welds Manual GTA Process
  - Inspected with Visual, Radiography, Penetrant
Weld Purging Equipment

- Inert gas purge required on both sides of weld joint for 2195 alloy
  - Existing tooling retrofitted
  - Narrow tooling gaps provided major challenges
  - Circumferential weld tools required very complex devices
- Mixture of Helium and Argon purge gas required on root side shield
- Pre-weld test developed for gas coverage adequacy
Selection of Weld Filler Wire Alloy

- Baseline 2319 Aluminum Filler until repair cracking discovered
- Survey/Testing conducted of Commercial Alloys
- 4043 Selected
  - Adequate Weld Strengths
  - Liquation Cracking Backfill/Healing Properties
  - Consistent Properties at Cryo Temperatures after significant cold work
- New NASA/LMC/McCook alloy B218 with higher ductility nearing maturity for implementation
Initial Weld Microstructure

Heat Affected Zone

Equiaxed Grain Region
Repair Weld Microstructure
The Initial Weld Fusion Line Microstructure was determined to be a major contributing factor for repair weld cracking.

The Initial Weld procedure and parameters were minor contributors as they affect "Time-at-Temperature which contributes to the amount of segregation that occurs."
Wide Panel Tensile Testing

- Small Structural Article developed to reveal stress distribution around repairs
- Instrumented with strain gauges and photoelastic material
- Results indicate residual stresses too high in repair for adequate load redistribution
- Some Wide Panel Tensile Testing data is now required for all 2195 weld repair development

Wide Panel Tensile Specimen
Planishing

• Planishing Required for all 2195 weld repairs
• Relieves Tensile residual stresses
• Drives Compressive stresses into repair
• Allows for stress redistribution around repair
New Metrics Developed for Planishing

- Planishing originally used on ET for distortion removal
- No metric existed other than removal of distortion
- Transverse Shrinkage Reduction Became new metric
- Adequate Strengths developed with 70% to 110% recovery
Manual Welder Training

- Smaller Grinds
- “Fast Hand” Technique
- Continuous wire feed
- Special Start/Stop Technique
Special Tooling for Weld Repairs

- Flat Position
  Determined Optimal Repair Position
- Vertical Position as a maximum case without defects
Sensor Technology Implemented

Optical/Laser based sensor system
Intersection Cracks

Crack Location

Barrel Weld (Ground Flush)
Intersection Crack Affected Tools

Hydrogen Tank Final Assembly Tool  Oxygen Tank Final Assembly Tool
Photomicrograph of Dual Cover Pass

Crack Susceptible Region Setup by Intersection

2219 Material
No Problem on Frame side

97B324 M-8

.320" Thick
Weld Lack of Penetration Issue

Weld Root

Hydrogen Tank Barrel Weld Tool
Development of Standoff Control

Spring Loaded VPPA Torch with SPAW Tungsten and Orifice Configuration

Manually Adjusted Mechanical Roller

Direction of Travel

Downhand SPAW with Trailing Wheel Mechanical Standoff
5016 Barrel Tool Configuration for SLWT

.025" Tungsten "Stick-in"
Toe Cracks Investigation

ROOT TOE 50X ORIGINAL MAG.

ROOT TOE 50X ORIGINAL MAG.
Forward Ogive Welding

- 0.190” – 0.220” thick tapered welds
- VPPA power supply has inconsistent reverse current
- Repairs require even faster manual repair travel speeds and narrow grinds

5012 Forward Ogive tool
Dome Cap Welding

• Oxygen Tank Dome Cap most challenging weld

• Hydrogen Dome Cap a close second.

• Peaking at intersections creates welding challenge

Dome Cap to Body Weld Tool
AI 2195 Welding Summary

Alloy Is More Reactive
  Root-side Inert Gas Purging Required
  Improved Cleanliness Helpful
  Automatic Arc Voltage Control More Sensitive
Alloy Is Crack Sensitive
  Reduced Heat Input Beneficial
  Filler Alloy Critical
Minimize Repair Grindouts
  Planishing Required If Filler Alloy Strength Is Mismatched

September 20, 2000
C. Jones
First SLWT Launched June 2, 1998

STS 91

- Eight Super Lightweight Tanks have flown
Developments to Improve Productivity

- Domes & Ogives return to 2219
- Friction Stir Welding to be implemented on Barrels
  - Lower Manufacturing Cost
  - Higher Weld Strength Margins/Less Variability
  - Lower defect rate
- Friction Plug Repairs
  - Higher Strength
  - Automated
- New Filler Alloy Developed
  - Improved Strength
  - Planishing Not Required