Lockheed Martin Advance Welding at Michoud Assembly Facility

Randy Brown
Lockheed Martin
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Welding Expertise at Michoud

- FSW on Thin Gage Aluminum (<0.100”) and Titanium
- Procurement of NCAM UWS I and PDS
- Produce 1st full scale FSW ET barrel
- FSW Development Programs
- 1st FSW at Michoud
- Soft Plasma Arc Welding used on External Tank
- Variable Polarity Plasma Arc Welding used on External Tank
- Tungsten Inert Gas Welding used on External Tank

Future
2000s
1990s
1980s
1970s

Lockheed Martin is an Industry Leader and Has Made Major Contributions to the Development of Joining Technologies
Friction Stir Welding Overview

- Frictional heating from the rotating tool plasticizes the material in the weld joint.
- The rotating tool then traverses along the weld seam, generating a high strength, solid-state (no melting involved) weld.

0.320-in Thick Al2219 FSW Macro

0.320-in Thick Al2219 Fusion Macro
### Friction Stir Welding Methods

<table>
<thead>
<tr>
<th><strong>Fixed Pin Tool</strong></th>
<th><strong>Adjustable Pin Tool</strong></th>
<th><strong>Self-Reacting Pin Tool</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Single piece tool&lt;br&gt; • Single thickness capability&lt;br&gt; • Requires a backing anvil</td>
<td>• Two Piece Tool&lt;br&gt; • Accommodates multiple thickness welds&lt;br&gt; • Requires a backing anvil</td>
<td>• Three Piece Tool&lt;br&gt; • Accommodates multiple thickness welds&lt;br&gt; • Requires less fixturing</td>
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- **Fixed Pin Tool**
  - Shoulder
  - Pin
  - Single Piece
  - Steel Anvil
  - Base Metal
  - Weld Direction

- **Adjustable Pin Tool**
  - Shoulder
  - Independent Pin
  - Upper Shoulder
  - Steel Anvil
  - Base Metal
  - Weld Direction

- **Self-Reacting Pin Tool**
  - Top Shoulder
  - Pin
  - Bottom Shoulder
  - No Backing Anvil
  - Base Metal

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**Michoud Capabilities Include All Methods of Friction Stir Welding**
Benefits of FSW vs Fusion Welding

Process Enhancements
- Reduced weld process time
  - Single pass up to 1” thick versus multiple passes for welds 0.250”+
- Fewer process variables / reduced variability
  - 3 main parameters versus 10+ for fusion
- Simplified joint geometry at thicker gages
- Easily automated & controlled
- Less operator dependent
- Eliminates consumables – no gases, tungsten electrodes, or filler metals
- Health hazards (i.e., arc burn, UV Radiation) are eliminated
- Reduced surface weld prep
- Weld bead geometry easier to inspect
- Easier to weld dissimilar alloys

Material Enhancements
- Mechanical Properties
  - Improved strength (10-30% increase)
  - Improved fracture toughness
  - Improved ductility
  - Reduced knock-down factors
- Reduced weld defects
  - Elimination of porosity
  - Elimination of solidification cracking
- Microstructural benefits
  - Parent material chemistry – no dilution from filler metals
  - Very fine-grains versus normal cast structure from arc weld
- Reduced shrinkage
- Reduced distortion
- Allow welding of traditionally unweldable alloys

0.320-in Thick Al2219 FSW Macro
Michoud FSW Experience and Capabilities

- **FSW Process Capabilities**
  - Fixed Pin
  - Adjustable Pin
  - Self-Reacting

- **Wide Range of Materials**
  - Al1XXX, Al2XXX, Al3XXX, Al5XXX, Al6XXX, Al7XXX
  - Ti alloys
  - Inconel 625, 718
  - Haynes 214
  - Stainless Steel

- **Wide Range of Thickness**
  - 0.015-in to 1.5-in plus tapers

- **Configurations**
  - Butt Joints
  - Lap Joints
  - T-Joints
  - Fillets

- **Wide Range of Part Configurations**
  - Linear, Complex Curvature, Circular, Spherical
Michoud utilizes microstructure evaluation to assess weld quality.
Basic Process Development

Design of Experiments used to Optimize Process

- **Phase I: Bounding Panels**
  - Broad range of weld parameters used to determine the limits for DOE

- **Phase II: Design of Experiment (DOE)**
  - 3 parameters at 5 levels (Low, Nom, High)
    - RPM, IPM, Forging Load
  - Resulting Data used for Evaluation
    - NDE and visual results
    - Mechanical properties (Ftu, Fty, Elongation)
    - Machine loads (Spindle Torque, Travel Load)
  - Trends and interactions are determined and used to define operating window

- **Phase III: Verification Welds**
  - Nominal and “edge of operating window” parameters
  - NDE, metallurgical and properties testing
  - Results in verification of the process parameters

Michoud uses a well-defined, rigorous approach to process development
Process Development System

Currently developing manufacturing processes for multiple structures and vehicles

- Capable of welding aluminum, steel, inconel and titanium alloys
- Capable of welding all friction stir welding methods from 0.025” to 2” thick
- Capable of welding parts that are 4’ x 10’ x 1 ½”
- Capable of welding complex configurations
  - Six (6) axes of motion

State of the Art Friction Stir Weld System Enables Innovative Research and Development
Universal Friction Stir Welding System (UWS I)

2003 NASA - NCAM - State of Louisiana Sponsored

State of the art tool with conventional, adjustable and self-reacting pin tool capability

• Horizontal 192”
• Vertical 246”
• Reach 118”
• Pitch -5º / +95º
• Roll +/- 15º
• Turntable 360” Diameter
• X-travel is expandable to 45 ft in length

The world’s largest FSW working envelope and most sophisticated capability
Universal Friction Stir Welding System (UWS II)

NCAM - State of Louisiana Sponsored
- Activated in 2009
- Similar to UWS I
- Includes system upgrades

Stationary stage: 21’x40’
Turntable: 21.8’ Dia.
Higher load capacities

- 7+ Axes of Motion
- Horizontal 682”
- Vertical 270”
- Reach 144”
- Pitch -5º / +95º
- Roll +/- 15º
- Turntable 264” D
- Floor Grid 204” x 480”
Michoud has Demonstrated Large Tankage and Structures for Multiple Applications
**External Tank Barrels**

- **Description**
  - Manufacture of 2195 External Tank Barrels using FSW
  - Over 650 feet of weldments per ET
- **Improvements**
  - Robust 0.320, 0.550 & 0.650 weld process
    - Extremely low defect rate
  - Strength/Ductility/Toughness
  - Tapered weld joints
  - Defect Free

*Photograph: Production 27.5’ Dia. ET Barrel Tools*

*All Longitudinal Barrel Welds Are Friction Stir Welded*
**Orion Crew Module**

- **Description**
  - Manufacture of Al2195/Al2219 External crew module
  - 100% Friction Stir Welded

- **Improvements**
  - Robust process
  - Strength
  - Ductility
  - Toughness

All Crew Modular Welds Are Friction Stir Welded
Cargo Floor, Bulkheads for C-130

- **Description**
  - Riveted structure replacement
  - Redesign and manufacture test articles
    - 7249 cargo floors (MAI program)
    - 7075 center wing bulkhead
- **Customer**
  - LM Aeronautics - Marietta
- **Challenges / Accomplishments**
  - Robust 0.080 & 0.150 weld process
  - Strength & ductility
  - Stress Corrosion (SCC)
  - Exfoliation Corrosion
  - Flatness
  - 20% Cost Reduction
  - Static Test at Vought Aircraft
    - Ultimate Load

*Friction Stir Welding performs as well or better than riveted structure*
Thin Gage Tank for Atlas

**Description**
- Friction Stir Lap weld three thin gage barrel sections together

**Challenges / Accomplishments**
- Lap and Butt Joints
- Thin Gage (0.080”)
- Traditionally unweldable alloy (2090)
- Internal Tooling only

**Enabling Technology for**
- H&RT Contract
- SDLV Upper Stage
- Wide Centaur Tank

Previously Unweldable, High Performance, Affordable Materials Are Now Available For Pressure Vessel Applications
Full Scale spun formed Dome Flow

- **Full scale dome (5+ meters)**
  - Two plates (20ft x 10ft x 0.750in) are FSWed together to form a single dome blank
  - Contour machining is done in an attempt to create a near net dome
  - 25 percent cost reduction over standard method of build

Post Process of Friction Stir Welds to Lower Costs and Increased Reliability
Second Forming Attempt (9/14/2009)

• Successfully formed full scale dome (5+ meters)
  — Two plates (20ft x 10ft x 0.750in) are FSWed together to form a single dome blank
  — 18-20 warm passes are performed to create the dome shape before SH&Q and final cold forming to create T8 properties

FSW

Blanks Welded together

Final ‘warm’ forming pass.

Ready for solution heat treat and quench
5.4ft dome depth.
Heat Exchanger / Ocean Thermal

• Description
  — Friction stir welded heat exchange
• Challenges / Accomplishments
  — Low cost heat exchanges
  — Welding of tube and shell heat exchanger
  — Thin wall tubes
  — Shell used as tooling
  — Low cost heat exchanges
  — Low corrosion rate than traditional welding

High Performance, Affordable Materials, Low Cost Heat Exchanger Applications
Industry Joining Applications

Shipbuilding & Marine

Aircraft
- Eclipse 500
- Silver Whisper
- C-130

Aerospace
- Shuttle External Tank
- Rig Crew Housing
- Tankers
- Delta II & IV

Other Applications
- Railway (Japan)
- Construction
- Automotive

Land Transportation
- AAAV
Friction Stir Weld Highlights

• **Friction Stir Welding (FSW) has revolutionized the weld process**
  – Enables **joining of traditionally non-weldable alloys**
  – Conventional, **adjustable and self-reacting techniques** enable a wide variety of joint types and gages

• **Process development is rapidly transforming into near- and far-term production implementation**
  – Ares I – Ares V
  – Orion – Commercial Space
  – Delta/ Atlas – Marine Applications

• **Michoud team brings together unique capabilities**
  – **Manufacturing expertise** plays role in R&D/ product development
  – **Innovative tooling concepts** enable various designs / reduce costs
  – **Nondestructive and destructive testing** readily available
  – **Statistical analysis** used to develop robust processes