Friction Stir Welding (FSW) and Hybrid Laser Welding (HLW) of Ti 6-4 Structural Components

Tim Trapp
Programs Manager – Government Programs Office

614.688.5231
tim_trapp@ewi.org
Acknowledgements

This work was completed under Army Contract # DAAD19-03-2-002 to investigate joining of complex structures using new advanced processes combined with modular tooling for rapid prototyping.

**EWI Staff:**
Jeff Bernath – FSW
Seth Krem – Tooling
Tim Li – FSW
Brandon Shinn – HLW
Tim Trapp – Project Manager

**Army Research Laboratory:**
Walter Roy – Program Manager
Outline

- Objectives
- EWI facilities
- Fixturing approach – Demmeler tooling
- Tool design for FSW of Ti 6-4
- Welding Ti 6-4 structural geometries
- Comparison of FSW, HLW and GMAW-P processes
- Fabrication of titanium structures
Objectives

- Develop the FSW process for structure applications for the Army’s Future Combat System (FCS)
- Produce single pass, full penetration FSW in Ti 6-4 up to ½-in. thick
- Fabricate a Ti 6-4 structure using FSW, HLW and Demmeler tooling
EWI Facilities

Conceptual model of manufacturing cell

Flexible Manufacturing Facility

- 10' x 14' x 36' working envelope
- Arc laser hybrid laser welding system
- Fanuc 120i robot and Lincoln Powerwave™
- 9 coordinated axes
- ARL sponsored
- Manufactured by Hawk Technology, Ltd. (Rock Island, IL)

Friction Stir Welding Facility

- 10' x 10' x 24' working envelope
- 35,000 lb axial plunge capacity
- 7 coordinated axes
- ARL sponsored
- Manufactured by General Tool Company (Cincinnati, OH)

FSW and robotic arc gantries at EWI with Demmeler tooling bed

Additional features (not shown)
- Shared work surface (19.5' x 12'), utilizing Demmeler system
- 5' x 10' Demmeler table with modular tooling package
- Romer portable CMM
- Rotary-tilt welding positioner
Demmeler Tooling

- Tooling designed for rapid prototyping with a high degree of accuracy
  - Precision bored tooling with a hole to hole spacing tolerance of 0.001"
  - Eliminates need for lengthy set up times by avoiding indexing, shimming and fit up issues
  - Common parts keep prices low and tooling adaptable for new uses
Multi-year study comparing nine (9) different tool materials for FSW of Ti 6-4

- Compromise of tool cost vs. tool life
- Cost Ranking (Least to Greatest) AE-5 & AE-6, AE-7 & AE-8, AE-9

(GE patented tool material, ref. US Patent No. 7,032,800)
Variable Penetration Tool (VPT)

- Designed to allow the FS tool to be plunged and retracted while traveling (without use of retractable pin tool)
  - Weld geometries of varying thicknesses
  - Eliminates keyhole at end of weld
  - Robust and simple design

Patent Pending
Docket No. 10/970,907
VPT for FSW of Ti 6-4

- (VPT) design incorporates tapered pin design
  - Significantly reduces tool wear and damage
  - Improves process robustness with greater operating window

- Tool material down selected from multi-year study
  - GE patented, low cost tungsten based alloy with acceptable tool life (AE-6)
FSW T-Joint Geometry

- T-Joint geometry tooling design and macro
  - Designed to produce an integral fillet weld on the inside (root) of the T-Joint geometry

Tooling designed for 0.25-in to 0.5-in thick Ti 6-4 T-joint

Macro with extruded fillets in root
FSW Corner Geometry

- Corner joint geometry tooling design and macro
  - 0.020-in. Ti 6-4 sheet used to ensure penetration without damaging the tool or backing anvil

Tooling Designed for 0.5-in. to 0.5-in. thick Ti 6-4 corner joint

Macro showing full penetration into 0.020-in. Ti 6-4 Sheet
Ti 6-4 Structural Geometries

- Butt, Corner and T-Joint example geometries

60-in. T-Joint

48-in. Butt Joint

24-in. Corner Joint
FSW XM777 Stabilizer Arm Demonstration Structure

Stabilizer Arm – Mock Section

0.188-in. Thick Ti 6-4
FSW, HLW, GMAW-P Process Comparison

- **FSW**
  - **Pros**
    - Single pass, full penetration weld up to 0.5-in
    - Completely solid state
    - Only basic butt joint fit up required
  - **Cons**
    - Extensive tooling required
    - Joint accessibility limited by machine design

- **HLW**
  - **Pros**
    - Single pass, full penetration weld up to 0.5-in
    - Lower heat input than GMAW or GTAW
    - More gap tolerant than laser only process
  - **Cons**
    - Fit up still an issue
    - Large # of process variables

- **GMAW-P**
  - **Pros**
    - Very adaptable to most weld geometries
    - Off the shelf technology
    - Lowest start up cost
  - **Cons**
    - Highest heat input
    - Multiple passes required
Legend
- Friction Stir Welds
- Hybrid Laser Welds
- GMAW-P Welds

Ti 6-4 Demo Hull Fabrication

Front Glacis

Lower Glacis

Angle Plate

Bulkhead

Outer Sidewall

Sponson

Inner Sidewall

Floor

EWI
THE MATERIALS JOINING EXPERTS
Inner Sidewall to Floor and Inner Sidewall to Angle Plate (FSW)

- Ti 6-4 corner joint with non-linear path geometry (0.5-in. to 0.5-in.)
- Single pass parameters:
  - 3.5-IPM Travel speed
  - 150-RPM Spindle speed
  - 3º Tilt
  - 0.535-in Penetration

Tooling model  Tooling assembly with welded part
Sponson to Outer Sidewall T-Joint (FSW)

- Ti 6-4 T-joint (0.25-in. to 0.5-in.)
- Single pass parameters:
  - 4-IPM Travel speed
  - 150-RPM Spindle speed
  - 3° Tilt
  - .325-in Penetration
Sponson to Lower Sidewall Corner Joint (HLW)

- Ti 6-4 corner joint (0.25-in. to 0.5-in.)
- Single pass parameters:
  - 17-IPM Travel speed
  - 215-IPM Wire feed speed
    - 0.035-in. wire
  - 4-kW Laser power

Tooling model

Tooling assembly with welded part
Outer Sidewall to Front Glacis Corner Joint (FSW)

- Ti 6-4 corner joint (0.5-in. to 0.5-in.)
- Single pass parameters:
  - 3.5-IPM Travel speed
  - 150-RPM Spindle speed
  - 3° Tilt
  - 0.535-in Penetration
Lower Glacis to Front Glacis Corner Joints (HLW)

- Ti 6-4 corner joint with multi-step path geometry (0.5-in. to 0.25-in. and 0.5-in.)
- Root pass (Laser only)
  - 20-IPM Travel speed
  - 4-kW Laser power
- Cap pass (HLW)
  - 15-IPM Travel speed
  - 215-IPM Wire feed speed
    - 0.035-in. wire
  - 2-kW Laser power

Tooling Model
Tooling Assembly with welded part
Bulkhead to Front Glacis/Outer Sidewall/Sponson/Inner Sidewall (GMAW-P)

- Ti 6-4 fillet joint with multi-step path geometry (0.5-in. to 0.25-in. and 0.5-in.)
- Fillet weld parameters:
  - 20-IPM Travel speed
  - 400-IPM Wire feed speed
  - 0.045-in. wire

Tooling Model  Final Assembly
FSW is capable of welding Ti 6-4 structural geometries in a single pass up to ~0.5-in. thick using newly developed tool materials and designs.

Demmeler tooling allows rapid, highly accurate set-ups with interchangeable parts.

Joining processes can be combined to create an all welded Ti 6-4 structure.

New alternative for machining intensive parts:
- Weld components to create a near net shape part
- Finish machine to print
Questions

Tim Trapp
Programs Manager – Government Programs Office

614.688.5231
tim_trapp@ewi.org