Robotic Friction Stir Welding

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Friction Stir Link
Robotic Friction Stir Welding

- **FSW Production System**

  ![Image of Standard Industrial Robot]

  **Standard Industrial Robot**
  - Low to Moderate Stiffness
  - Flexible: Open Architecture
  - Good Working Envelope
  - **Low Cost**
Robotic Friction Stir Welding

- **Tower Automotive Robotic FSW System**

- ABB IRB 6400PE Robot (75 kg payload)
- 7 kW Hydraulic Pump
- 7 kW Hydraulic Motor (0 - 3600 RPM)
- Tower fabricated spindle
- Multi-directional speed control
- Force control without external force sensor (software based)
Robotic System Challenges

- Oscillatory motion
- Required motor torque a function of spindle size
- Path Deflections
  - Vertical
  - Lateral

Robotic Friction Stir Welding

Robotic Weld w/ Uncontrollable Oscillation
Robotic Friction Stir Welding

**Force Control**

\[ F_c = \text{commanded force} \]
\[ F_a = \text{actual force} \]
\[ F_e = \text{force error} \]
\[ \Delta D = \text{commanded change in plunge depth} \]

Software force feedback!
Force Control on IRB6400

- Motor currents (torque) measured
  - Actual force calculated
  - Sample Rate = 2 Hz

Robotic FSW Thrust Load

- Weld Starts
- Traverse Start
- Void Initiation
- Weld w/o Force Control Active
- Actual Force w/ Feedback
- Commanded Force
- Actual Force w/o Feedback

Sample Rate = 2 Hz
Multi-Dimensional Capability
ABB IRB 6400 Capability

- 3D capability proven
- Travel speeds ~ 2 m / min on 2mm to 2 mm lap weld
- Force control satisfactory
  - Need higher sample rate
  - Does not work on plunge
  - Overcomes vertical deflection
- Side deflection compensated for in program
Robotic FSW Application: Tailor Welded Blank

- Material use optimization
- Varying thickness
- Varying alloy
- Requires 5 Degree of Freedom (DOF) machine

Thick Blank

Thin Blank

Dissimilar Thickness Butt Weld

Example TWB
Robotic FSW of TWB

- Robot required (need 5 DOF)
  - Welds made from “stepped” side
  - Non-zero travel (pitch) and work (roll) angle

- Joining of 1 mm to 3 mm range 6061-T6, 6111-T4, 5754-O, 5182-O, 5082-O, etc.
FSW TWB Challenges

- Standard butt weld tool design not ideal for TWB application
- Optimal travel and work angle determination difficult
  - Large travel and work angles
  - Small work angles
  - Small travel angles
- Pin length
- Rotation direction effects
- Flash easy to generate
Robotic FSW of TWB: Accomplishments

- Joint efficiencies of 80% to 100%
- Travel speeds up to 1.8 m/min
- Joint thickness combinations from 1 to 3 mm
- Numerous alloys
- Production simulation trials w/ over 1250 meters of welding

Failure in HAZ and thinned section
- **ABB IRB7600**
  - New Robot
  - Maximum payload rating 500 kg
  - Same working envelope and maximum speed as IRB6400
  - PC based controller
Robotic Friction Stir Welding

- ABB IRB7600 FSW Testing
ABB IRB7600 Testing

- Significantly stiffer
- Much higher force capability
- Able to weld 6.4 mm material (6061-T6) at 17 mm / sec (1 m / min)
- Able to weld 3.1 mm to 3.1 mm 2024-T3 (lap weld) at 5 mm / s
- Tool pin failure & hydraulic unit now limiting factors
- Force control loop sample rate > 15 Hz
Conclusions

- Industrial robots can perform FSW!
  - Travel speeds > 2 m / min
  - Material thickness up to 6 mm
- Force control is critical to success of robotic FSW
- Open architecture is an enabling feature for FSW using an industrial robot
- Robot flexibility with work and travel angles important
  - Flash minimization
  - Gap tolerance
  - Material thickness offsets