Pin Tool Geometry Effects in Friction Stir Welding

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Abstract

In friction stir welding (FSW) there is significant evidence that material can take one of two different flow paths when being displaced from its original position in front of the pin tool to its final position in the wake of the weld. The geometry of the pin tool, along with the process parameters, plays an important role in dictating the path that the material takes. Each flow path will impart a different thermomechanical history on the material, consequently altering the material microstructure and subsequent weld properties. The intention of this research is to isolate the effect that different pin tool attributes have on the flow paths imparted on the FSWed material. Based on published weld tool geometries, a variety of weld tools were fabricated and used to join AA2219. Results from the tensile properties and microstructural characterization will be presented.
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Motivation

Minimize testing & increase productivity.

- Weld Schedule
- Process Variables
  - Pin Tool
  - Process Parameters
  - Modify
- Experiments
  - Analysis
  - Fails Allowables
  - Passes Allowables

Stress-Strain

Motivation

Minimize testing & increase productivity.
Problem Statement

Determine how pin tool attributes affect material flow.

threads

0°

15°, 30°, 45°, & 60°

Other features: flats
Transverse Macrographs of AA2219 FSWs

AS

0 deg, threaded
200 rpm, 4.5 ipm, 7000 lbf

RS

0 deg, no threads
200 rpm, 1.8 ipm, 4000 lbf

60 deg taper
400 rpm, 7.1 ipm, 5500 lbf
Reported Weld Tool Designs Vary with Material Joined

<table>
<thead>
<tr>
<th>Weld Tool Geometry</th>
<th>Al</th>
<th>Ti</th>
<th>Steel (HMTM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_s/D_p$</td>
<td>2.4</td>
<td>1.2-3.8</td>
<td>2.3-2.4</td>
</tr>
<tr>
<td>$D_p/L_p$</td>
<td>1.5</td>
<td>1.4-1.9</td>
<td>1.7-2.0</td>
</tr>
<tr>
<td>Pin surface</td>
<td>threads</td>
<td>smooth</td>
<td>smooth</td>
</tr>
<tr>
<td>Taper (deg)</td>
<td>0</td>
<td>30-60</td>
<td>30-60</td>
</tr>
</tbody>
</table>

Diagram showing the geometry of a weld tool, with labels for $D_s$, $D_p$, $L_p$, shoulder, and pin.
Tapered Weld Tools Can Create Rotational/Stir Zone

\[
F_n \equiv F \cos(90^\circ - \theta)
\]

\[
F_p \equiv F \sin(90^\circ - \theta)
\]
Stresses Predicted to Increase Along Shear Line With Increasing Taper

Software: Ansys

Solution:
- Axisymmetric,
- Large deformation

BCs: Symmetric

Assumptions:
- Prescribed displacement,
- No slip
Investigate Differences in Material Flow Path Using Taper Rather than Threaded Pin

Weld Tools: MP159 & WCCo

<table>
<thead>
<tr>
<th>Ratio&amp;Tapers</th>
<th>MSU</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_s/D_p$</td>
<td>1.75</td>
</tr>
<tr>
<td>$D_p/t_{mater.}$</td>
<td>1.4</td>
</tr>
<tr>
<td>Taper ($\theta$)</td>
<td>$0^\circ, 30^\circ, 60^\circ$</td>
</tr>
</tbody>
</table>
FSW Test Matrix for AA2219-T87

<table>
<thead>
<tr>
<th>RPM</th>
<th>Travel Speed (in/min)</th>
<th>Forge force (lbf)</th>
<th>Travel Speed/rpm (in/rev)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0°</td>
<td>30°</td>
</tr>
<tr>
<td>200</td>
<td>1.8</td>
<td>4000</td>
<td>3500</td>
</tr>
<tr>
<td>300</td>
<td>4.0</td>
<td>4000</td>
<td>3500</td>
</tr>
<tr>
<td>400</td>
<td>7.1</td>
<td>4000</td>
<td>3500</td>
</tr>
<tr>
<td>500</td>
<td>11.1</td>
<td>4000</td>
<td>3500</td>
</tr>
</tbody>
</table>

\[ PHI = \frac{rpm^2}{Travel \ Speed} \]

PHI – Pseudo heat index, qualitative comparison for heat input

S. Kandukuri et. al., Friction Stir Welding and Processing IV, TMS Annual 2007
Tensile Specimens Machined to Eliminate Parent Material in Gage Section

0.160/0.140 in

5 in

0.4 in
Weld Tool Geometry Strongly Affects Consumed Power

Power = $2\pi f \times \text{Torque}$  \hspace{1cm} f = \text{frequency (rpm)}

![Bar chart showing the power consumption for different tool geometries and in/rev values.](chart.png)
Tensile Strength Increases With in/rev Until Defects Occur
Typical Grain Refinement Observed in all Welds

AA2219-T87

Parent Material
Grain Size = 100-200 μm

Nugget Zone
Grain Size = 4-7 μm
FSW Defects Observed at Highest RPM and TS

60° Pin Tool
500 rpm & 11.1 ipm

30° Pin Tool
500 rpm & 11.1 ipm

0° Pin Tool
500 rpm & 11.1 ipm
Investigate Function of Flats in FSW

Swept volume: W.M. Thomas et. al., TMS2001: Aluminum and Joining Sessions
Summary

- Refined grains were observed in all AA2219 FSWs.
- Similar joint efficiency was achieved for all tools evaluated.
- Two tools were down selected and used in FSWing of Ti-6Al-4V.
- Analysis of weld data with incorporated flats in the weld tool is on going.
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