Phased Array Ultrasound

Initial Development of PAUT Inspection of Self-Reacting Friction Stir Welds

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Background

Conventional Friction Stir Weld (FSW)

- Uses fixed or retractable pin tool
- One shoulder and an anvil
- Requires more tooling force

Self Reacting Friction Stir Weld (SR-FSW)

- Uses self reacting pin tool
- Two shoulders. No anvil.
- Uses less tooling force and lower rpms.
Previous Work

• 2003-2004
  – NDE development for inspection of SR-FSW in 0.320-inch-thick 2219-T87/2195-T8M4.
  – Develop volumetric techniques for residual oxide defects (ROD) and other void type flaws via phased array ultrasonic testing (PAUT) to assure the acceptable quality of SR-FSW.
  – Multiple techniques were evaluated: visual (VT), penetrant (PT), X-ray radiography (RT) and phased-array ultrasound (PAUT).

<table>
<thead>
<tr>
<th>Weld Defect</th>
<th>Possible Cause</th>
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<tbody>
<tr>
<td>Defect free (clean)</td>
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<tr>
<td>Residual Oxide Defect (ROD)</td>
<td>Improper weld joint cleaning/Unconsumed interface</td>
</tr>
<tr>
<td>Voids / Wormholes</td>
<td>Insufficient forging of weld nugget</td>
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<tr>
<td>Tears – surface and subsurface</td>
<td>Excessive forging force</td>
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<tr>
<td>Undercutting</td>
<td>Excessive heel plunge</td>
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Table 1. Defects studied
Residual Oxide Defect (ROD)

- PAUT is the only NDE method which has been shown to detect detrimental levels of ROD.
- Detrimental ROD results in significant decrease in weld strength.
- Several process control countermeasures exist
  - Pre-weld prep including cleaning of weld area and dwell time.
  - Offset of centerline of weld.
  - Type of pin tool?

[Images of ROD Fracture and Typical Fracture]
Previous Work

• Conclusions
  – RT was inadequate for inspection of ROD
  – PAUT
    • ROD from high to mild severity, but non-relevant indications (NRI) were also noted
    – Surface breaking flaws were detected by visual and PT but PT produced multiple NRI. RT and PAUT found severe surface breaking flaws.

• Recommendations
  – Continue PAUT development to encompass ALL internal and volumetric flaw types.
  – Establish NDE thresholds for worst case flaws, and develop interpretation criteria based on these thresholds to include ROD, void and internal flaws.
Orion PAUT Development

• Initial Development
  – Based on previous work to develop PAUT as the primary NDE method for SR-FSW
  – Ground Test Article (GTA)
    • First complete engineering article of the Orion Crew Module (CM)
    • GTA provides the opportunity to test and qualify the baseline PAUT process.
    • Qualification of GTA inspection will serve as input for qualification of flight hardware inspection.
Development Defects

• Two Classes
  – Out of Schedule Defects (e.g. depend on weld temperature, mixing, etc.)
    • Galling
    • Lack of Adequate Forging (LAF)
    • ROD
    • Wormholes
  – Contamination Defects
    • Heavy Inclusions
    • Organic Material
Phased Array Ultrasound Analysis

C scan
(top view)

B scan (side view)

D scan
(end view)

Weld Nugget

A Scan
(Amplitude)
PAUT Process

• Inspection Methods
  – Phased Array UT
    • Focus
      – Reference Standard: 0.020” Side Drilled Hole (SDH)
      – 10L64 (10 MHz, 64 element) probes with water wedge
      – 0° skew angle (perpendicular to direction of pin travel)
      – Dual probe, one each on advancing and retreating sides of weld, automated track encoder
      – 45° shear wave, electronic scan
    • OmniScan
      – 0.020” SDH Reference Standard
      – 5L 64, 10L 64 and 17L 100 probes with contact wedge
      – 0° skew angle
      – 45° shear wave, electronic scan
      – Hand scan on advancing and retreating sides with mini-encoder
Galling

- Tears and/or blisters on the surface (root or crown) of the SR-FSW

No Defect Visible

X-ray
Wormholes and LAF

- Typically occur along advancing side of the weld midline
- Cold welds
ROD/Cross Slide

• Pin tool offset to the advancing side
• Creates larger volume of unconsumed interface
• Panels with increasing degree of offset
  – 10 % → 50 %
• Can resemble LAF in extreme conditions
ROD
30% Offset

No Defect Visible

X-ray
ROD

50% Offset

No Defect Visible

X-ray
Contamination

- Heavy Inclusions – Wire brush bristles, pin tool fragments
- Organics – Oil, hydraulic fluid
Weld Development DOE

• Correlate weld strength and NDE results
• Weld Schedule for 0.200” thick Al 2195/2195
• External Tank (ET) PAUT protocols were followed
  – Reference Standard: 0.020” Side Drilled Hole (SDH)
  – 10L64 (10 MHz, 64 element) probes with water wedge
  – 0° skew angle (perpendicular to direction of pin travel)
  – Dual probe, one each on advancing and retreating sides of weld, automated track encoder
  – 45° shear wave, electronic scan
Mean UTS Values for DOE I & II

- Minimum acceptable UTS (red line above) per Engineering Process Specification
Mean UTS Values for DOE I & II

Orion DOE (5/16 DUST pin, 2:1, 95/95, .200) UTS

- Green squares were rejected by x-ray radiography
Mean UTS Values for DOE I & II

Orange squares were rejected by PAUT
Captured all of X-ray rejected defects (circled in green)
False positives had localized defects and/or insufficient surface preparation
Representative Metallurgy

- Acceptable

- Galling

- LAF
Conclusions

• Weld DOE
  – All welds rejected by PAUT were outside the nominal weld schedule
    • Low UTS
    • Fracture Location in Weld
• X-ray was not successful at rejecting all major defects
• PAUT has shown initial success at finding all classes of defects in SR-FSW