Description of a Pre-Rotation Defect in FSW of 19mm 5456-H116 Aluminum

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Background/Objectives

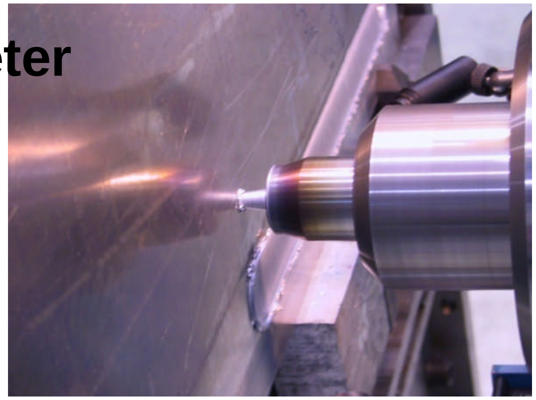
- **Friction stir welding (FSW) has been demonstrated in many aluminum alloys and material forms.**
- **Welding parameters needed material/thickness and welding tool design to confirm joint properties and tool life.**
- **A detailed characterization of FSW'd 19mm 5456-H116 was needed to determine the suitability of this technique for a Navy application.**

<u>Objectives</u>

- **Develop optimum welding parameters and tool design**
- **Characterize joint properties**
  - **<u>Static tensile strength and ductility</u>**
  - **<u>General corrosion</u>**
  - **<u>Stress corrosion cracking</u>**
  - **<u>Distortion</u>**

Welding Trials

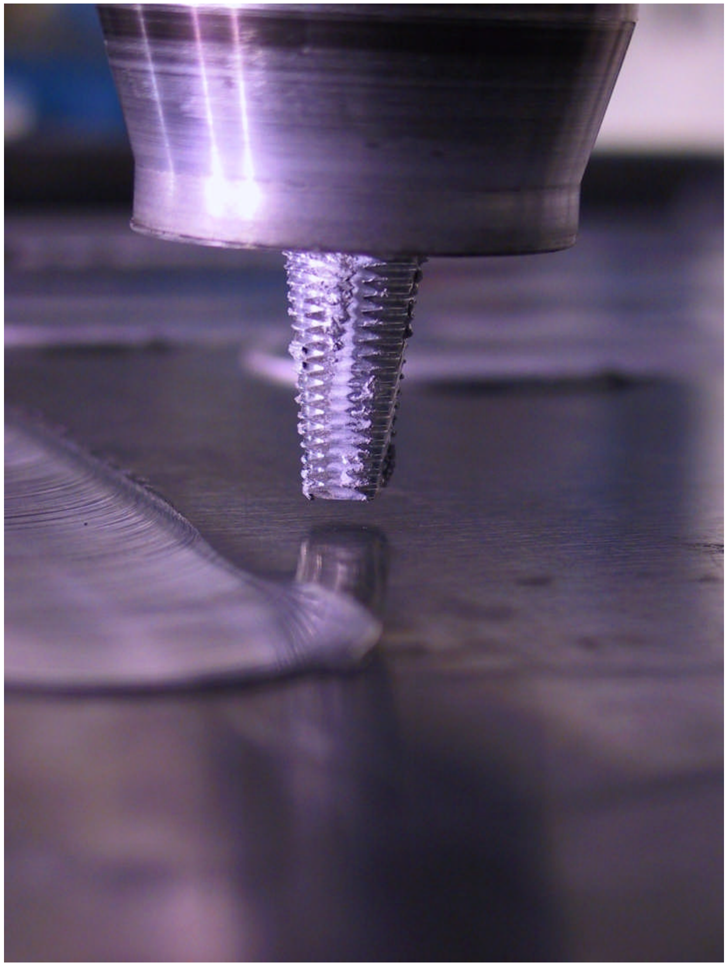
- **Preliminary welds**
  - **35.6mm shoulder/17.3mm pin diameter for all welds**
  - **190mm/min travel speed with 460, 440, 415, 381 rev/min spindle**
  - **127mm/min travel with 310, 280, 250, 230 rev/min spindle (the travel speed was reduced to maintain travel/rotation ratio)**
  - **Welds sectioned to reveal stir zone structure**
- **Two rounds of welding trials conducted**
  - **Round 1 : 35.6mm shoulder/17.3mm pin diameter**
  - **Round 2 : 30.5mm shoulder/17.3mm pin diameter**
  - **Welds tensile tested and sectioned**



Welding Trials – Round 1

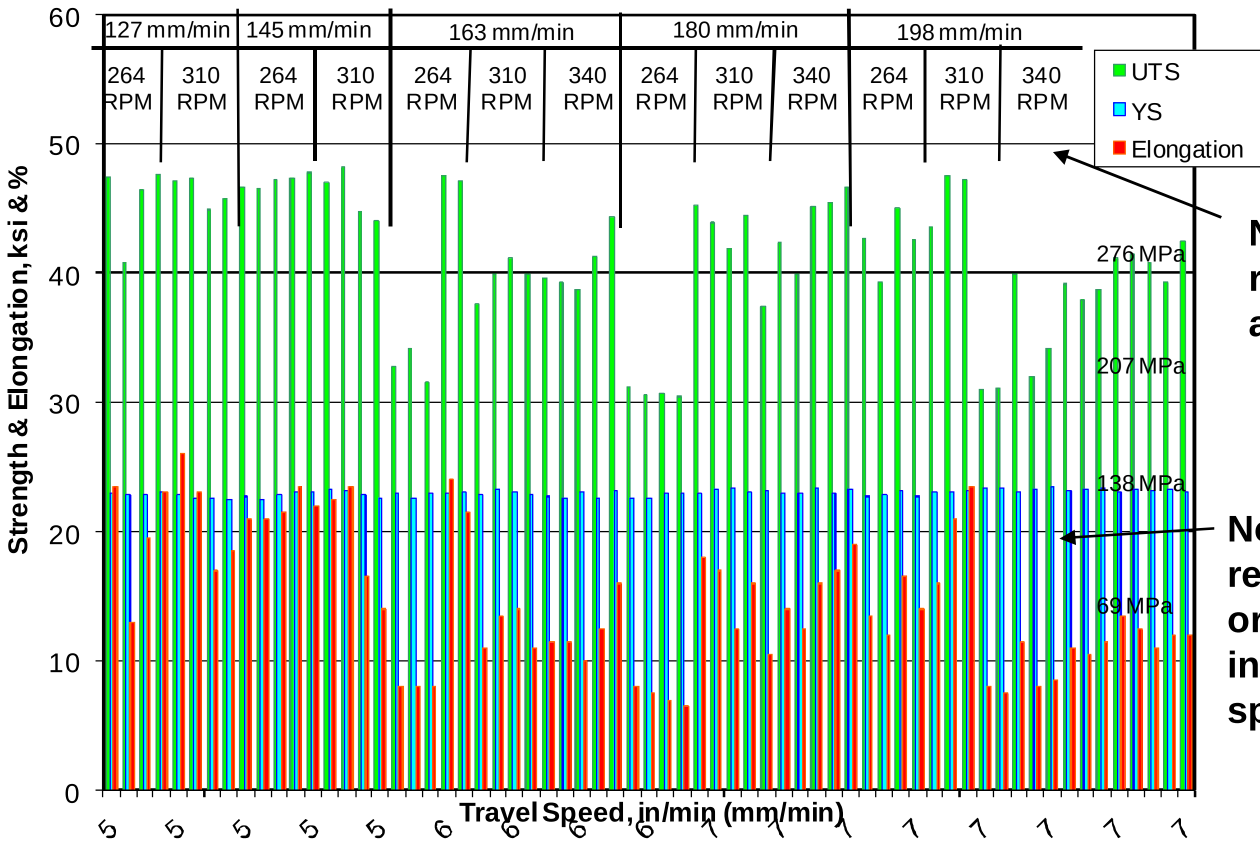
- **Frustum-shaped pin with flat, scrolled shoulder**
- **Tool design not optimized**

Shoulder Parameters	
Shoulder diameter, mm	35.6
Scroll depth, mm	1.3
Scroll pitch, mm	3.3
Scroll width, mm	1.27
Number of spirals	1
Pin Parameters	
Nominal pin length, mm	18.5
Pin maximum diameter, mm	17.3
Pin minimum diameter, mm	9.7
Thread pitch, threads/mm	18
Number of pin flats	4



Results – Round 1 Welding Trials

- **Round 1 welds exhibited high strength and ductility**
- **Welds also had high variability, both between welds and within individual welds**

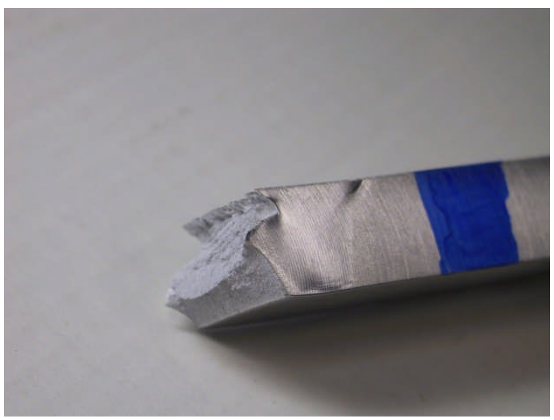


Note: Each category represents results from a single weld

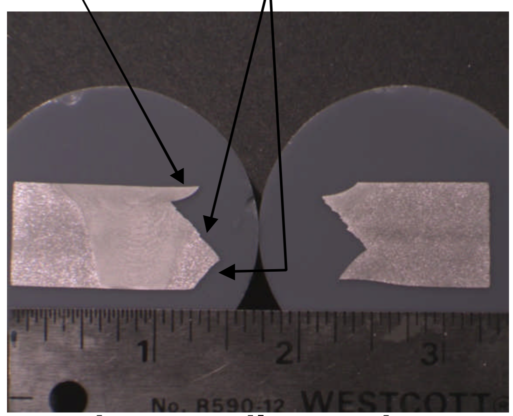
Note: Each bar represents the strength or ductility of an individual tensile specimen

Round 1 Weld Variability

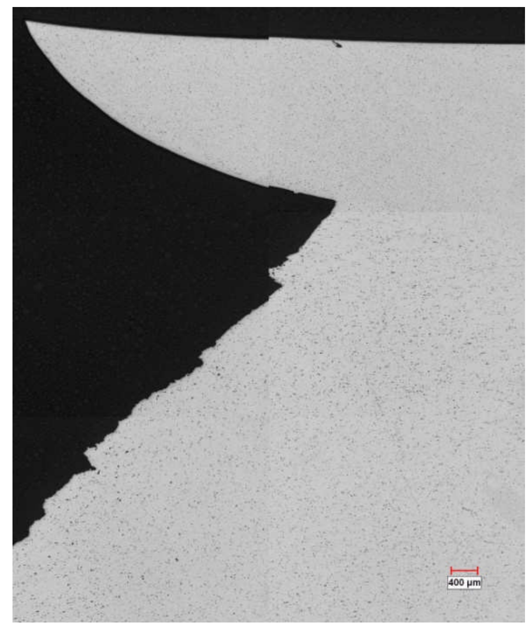
- **Inspection of fracture surfaces revealed that low-strength tensile specimens all had a similar fracture pattern**
- **Fracture initiated in the crown of the weld**
- **Inspection of metallographic sections revealed that the fracture initiated along a remnant oxide band in the upper stir zone.**



Broken tensile specimen

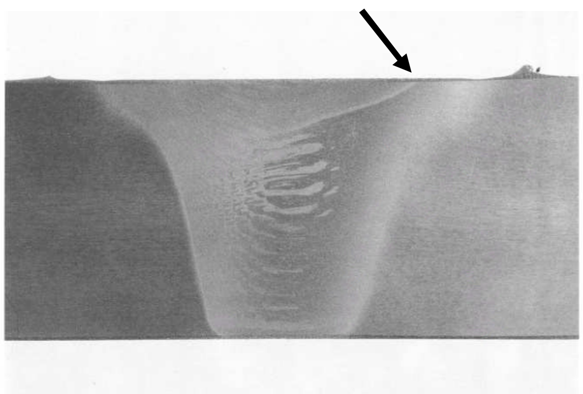


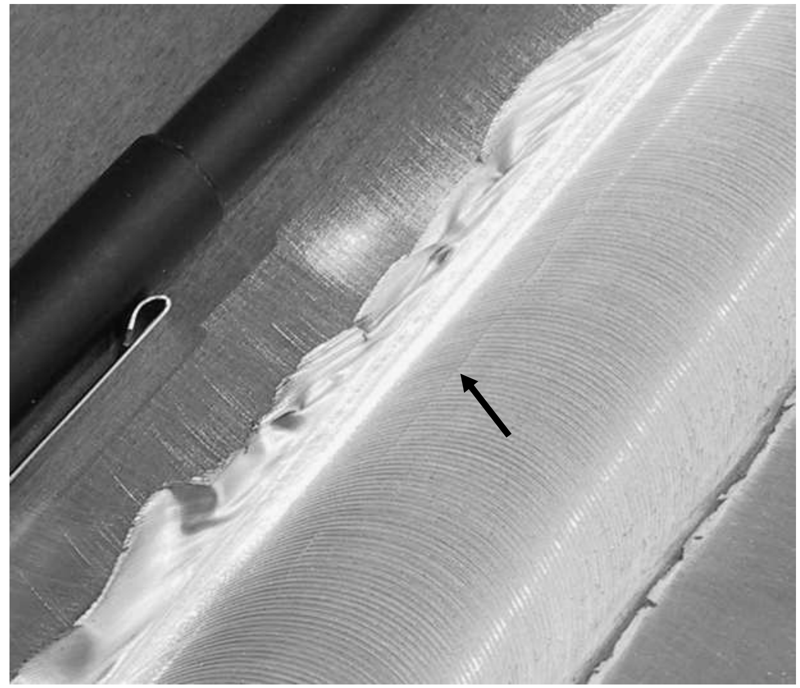
Broken tensile specimen, sectioned and mounted



Round 1 Weld Variability

- Inspection of weld crown surfaces showed discontinuous, surface cracking is some welds
  - Biased toward retreating side of weld crown
  - Aligned with microstructural feature

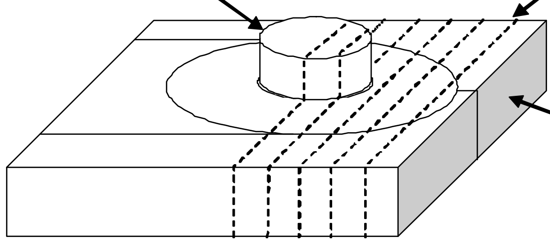




Discontinuous surface crack

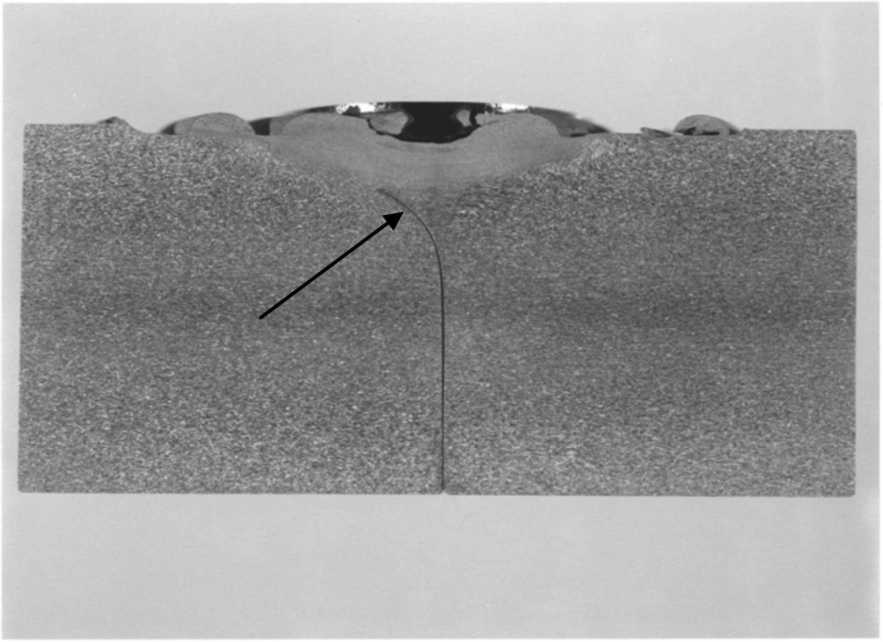
Hypothesis – Joint “Pre-Rotation”

- **Excessive shoulder diameter led to early rotation of joint – far in advance of pin**
  - **Reduced maximum temperature**
  - **Reduced strain?**
- **Serial sectioning study conducted**
  - **“Stop action” weld**
  - **Remove shoulder component**
  - **Section weld end in series of transverse sections**



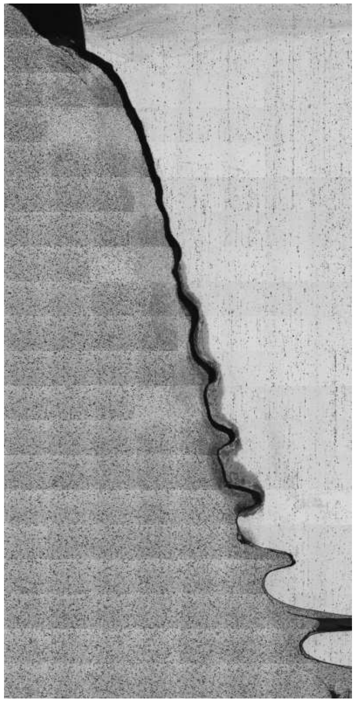
Serial Sectioning Results

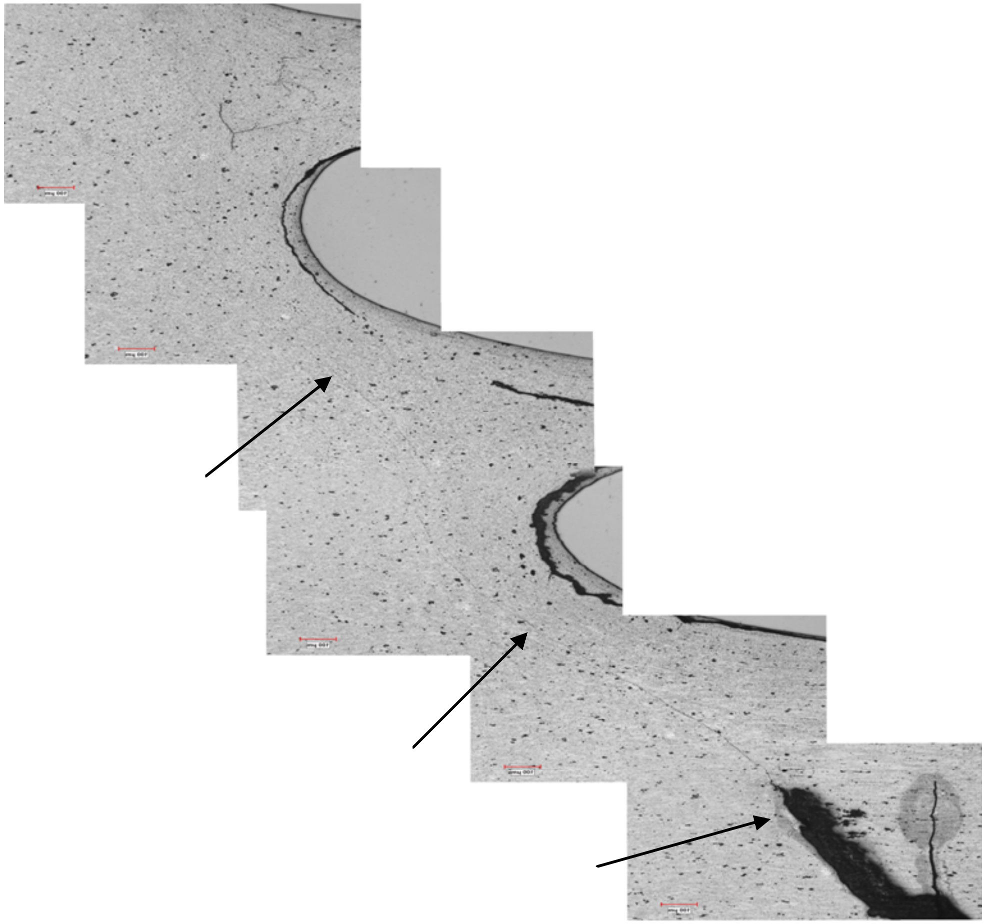
- Upper portion of joint was deformed to retreating side immediately upon interaction with shoulder
- As pin approached, more deformation out of pin path



Serial Sectioning Results

- **Remnant oxide band visible, but tightly compressed near pin in lower portion of the weld**





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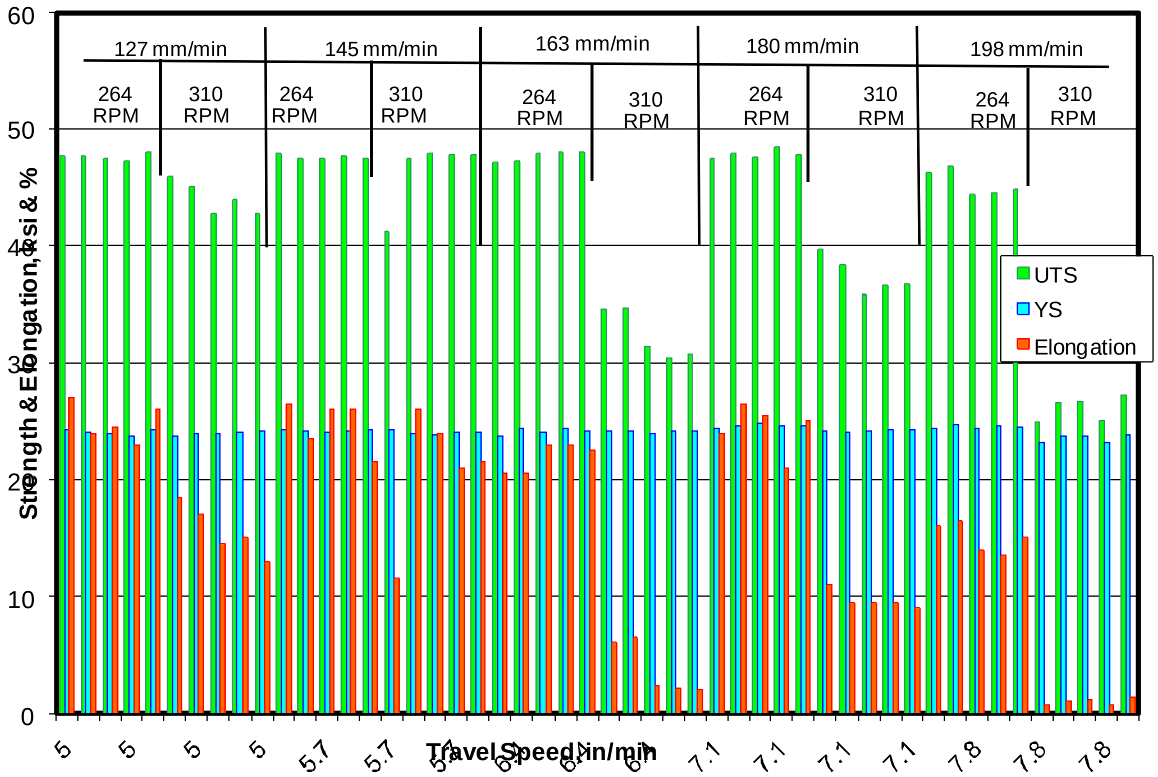
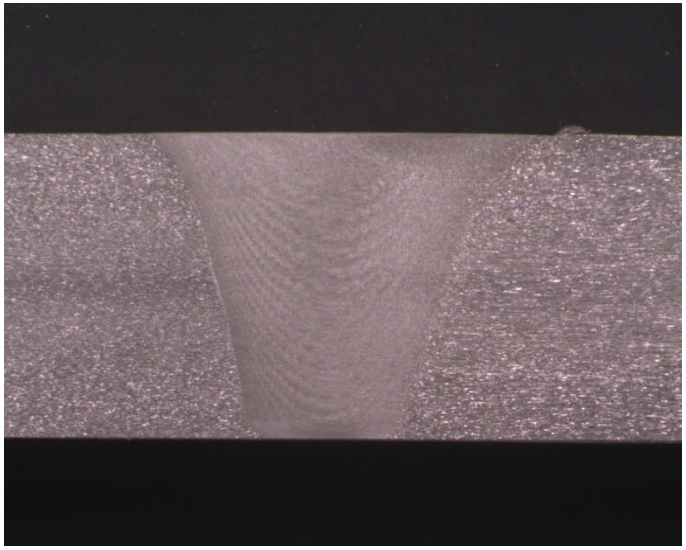
Round 2 Welding Trials

- 2nd round of welding trials used 30.5mm shoulder diameter instead of 35.6mm, with same pin design
- Welds showed much lower variability, especially at 264 rev/min

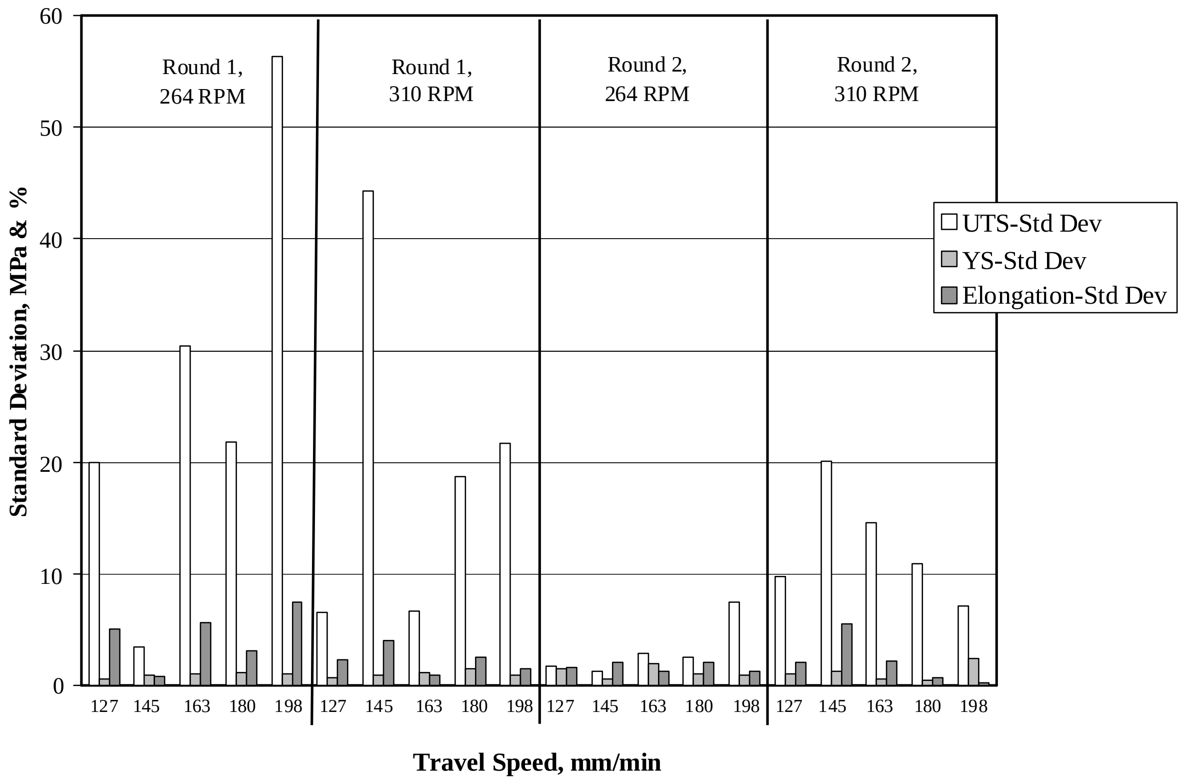




Macro section from round 2
6.4 in/min, 264 rev/min
Note elimination of oxide band

Round 2 Welding Trials

- **Dramatic reduction in weld strength and elongation variability, especially at 264 rev/min for all travel speeds**

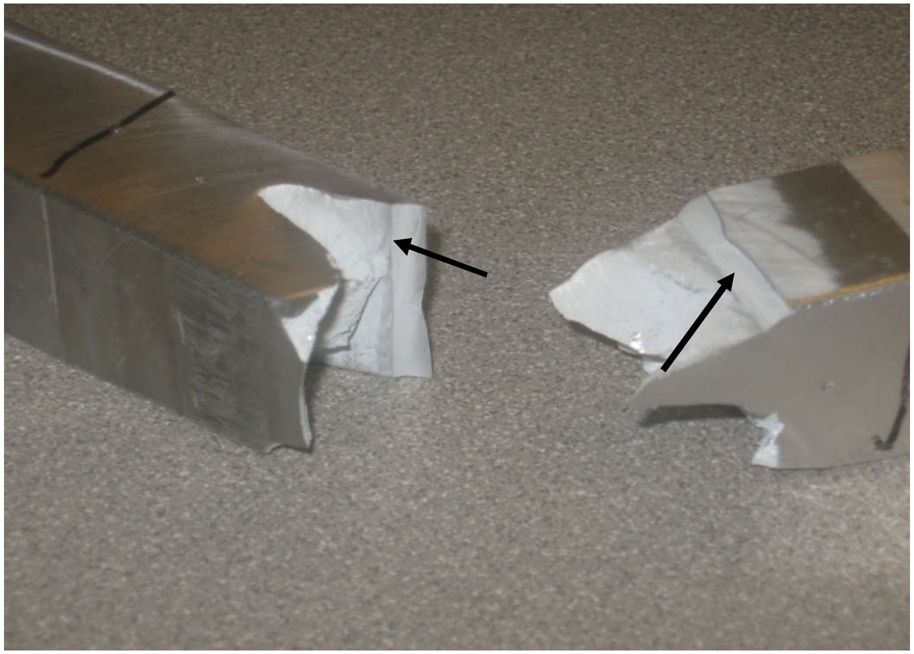


Other Cases of Pre-Rotation Defects?

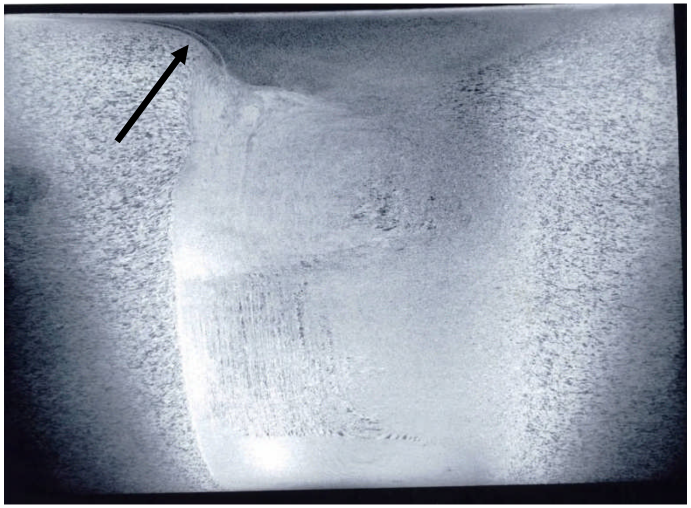
- Fonda, et al., noted anomalous low tensile results in 5456 FSW, attributed to entrained oxide, but not described in detail. No other mention of this effect for 5083 in literature examined.
- Similar fractures observed in unpublished study (2000):
  - 25.4mm thick 2519-T87 Al plates
  - 45.7mm shoulder diameter
  - Load control, tilted tool
  - 20 and 30.5 mm/min travel speed (very slow by today's standards)

25.4mm 2519-T87 FSW (2000)

- **Fracture initiated in crown, biased to advancing side**
- **Microstructural feature also observed**

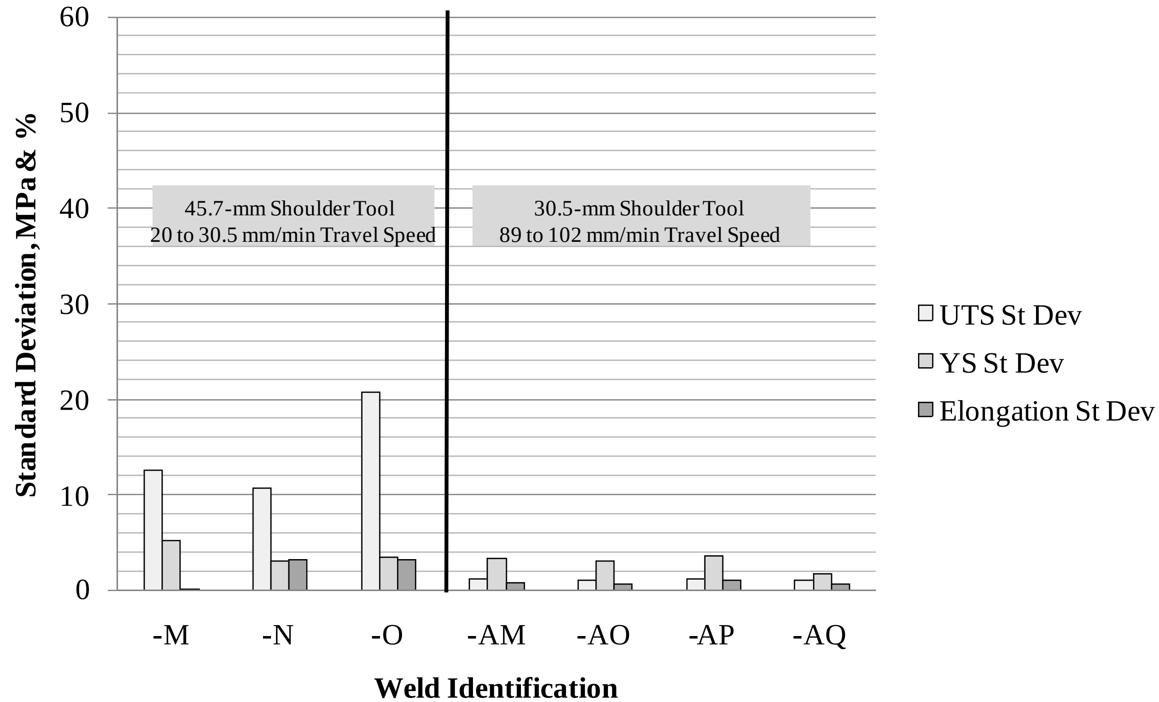


Advancing side **Retreating side**



25.4mm 2519-T87 FSW (2000)

- **Optimized welds showed much lower strength variability**
- **Smaller shoulder (30.5mm vs. 45.7mm), higher travel speed (102 mm/min vs. 30.5mm)**



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Discussion

- Common to observe remnant oxide artifacts in FSW of aluminum alloys, without participating in fracture of transverse tensile tests
- Proper welding process development can be expected to confirm suitability for service conditions
- However, pre-rotation defect formation can degrade performance
  - Post-weld plastic deformation in service (ballistic impact)
  - Post-weld plastic deformation in down-stream manufacturing processes (rolling, forming operations)

Conclusions

- Good joint properties were achieved in 19mm 5456 Al, with high strength and ductility, for a range of travel speeds.
- High joint strength variability, crown-associated fracture initiation, microstructural feature suggested intact oxide band that degraded strength
- Serial sectioning study confirmed this root cause
- Subsequent testing with smaller shoulder reduced oxide band to insignificant level
- Possible other cases of pre-rotation defects noted in earlier studies