Friction Stir Welding of Stainless Steel and Nickel Base Alloys

R.J. Steel, T.W. Nelson, C.D. Sorensen, Y.S. Sato, C.J. Sterling, and S.M. Packer

Acknowledgements

Material provided by:

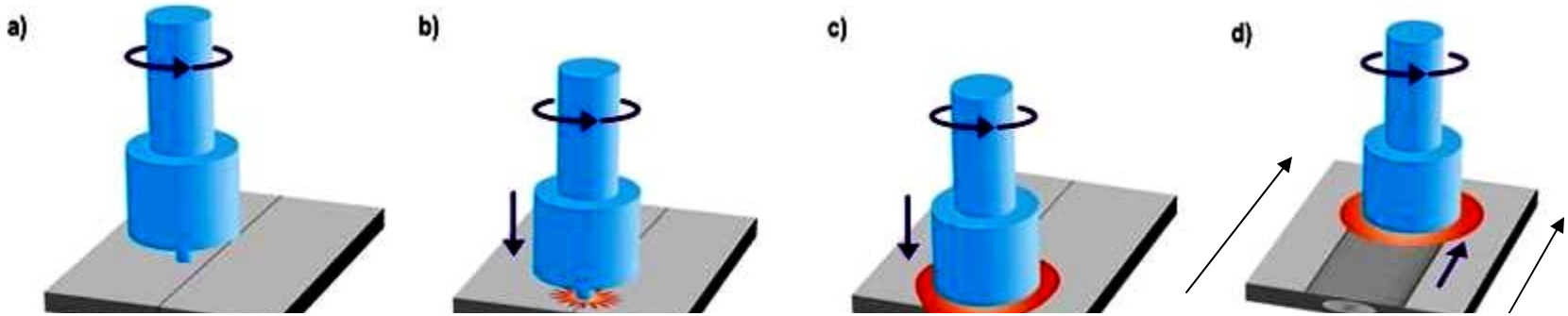
- Haynes International
- Ulbrich
- Sandvik

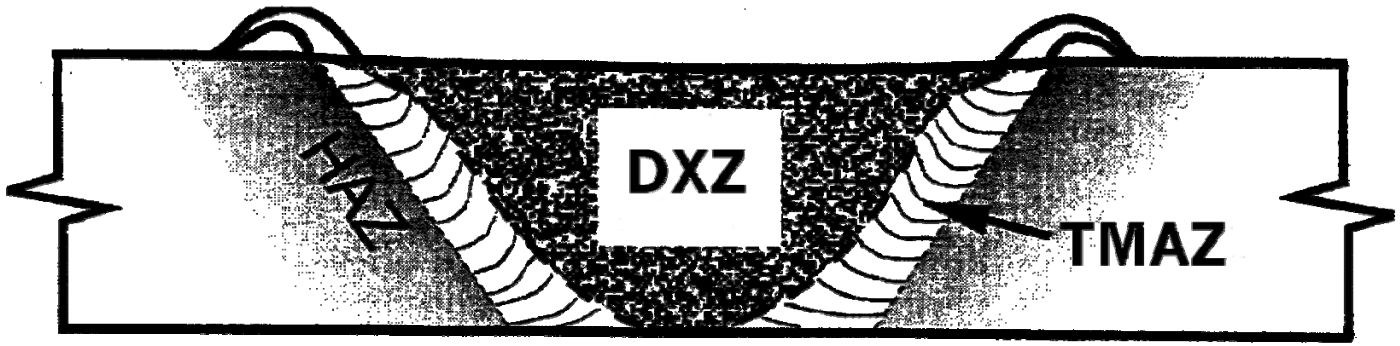
Outline

- Friction Stir Welding
- Polycrystalline Cubic Boron Nitride (PCBN)
- Experimental Approach
- Results
  - Stainless Steel
  - Super Duplex Stainless Steel
  - Nickel Base
- Tool Life
- Summary

Friction Stir Welding

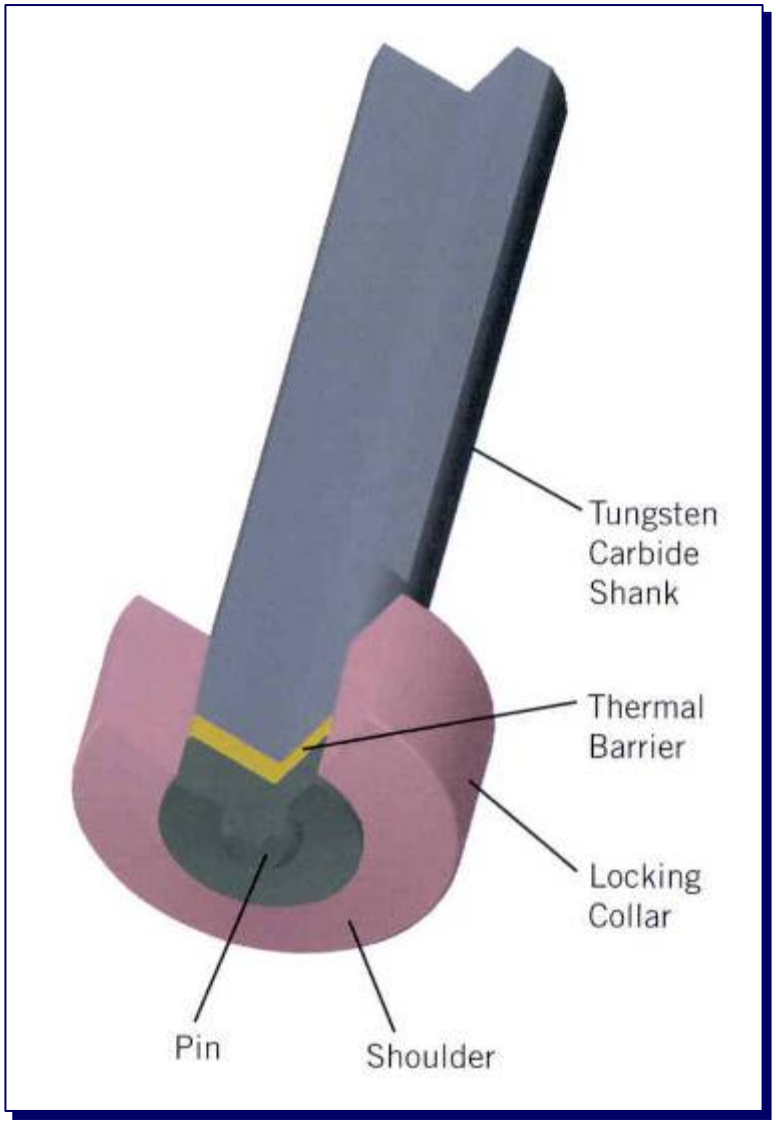
- Solid state process
- Important tool features
  - Shoulder and Pin



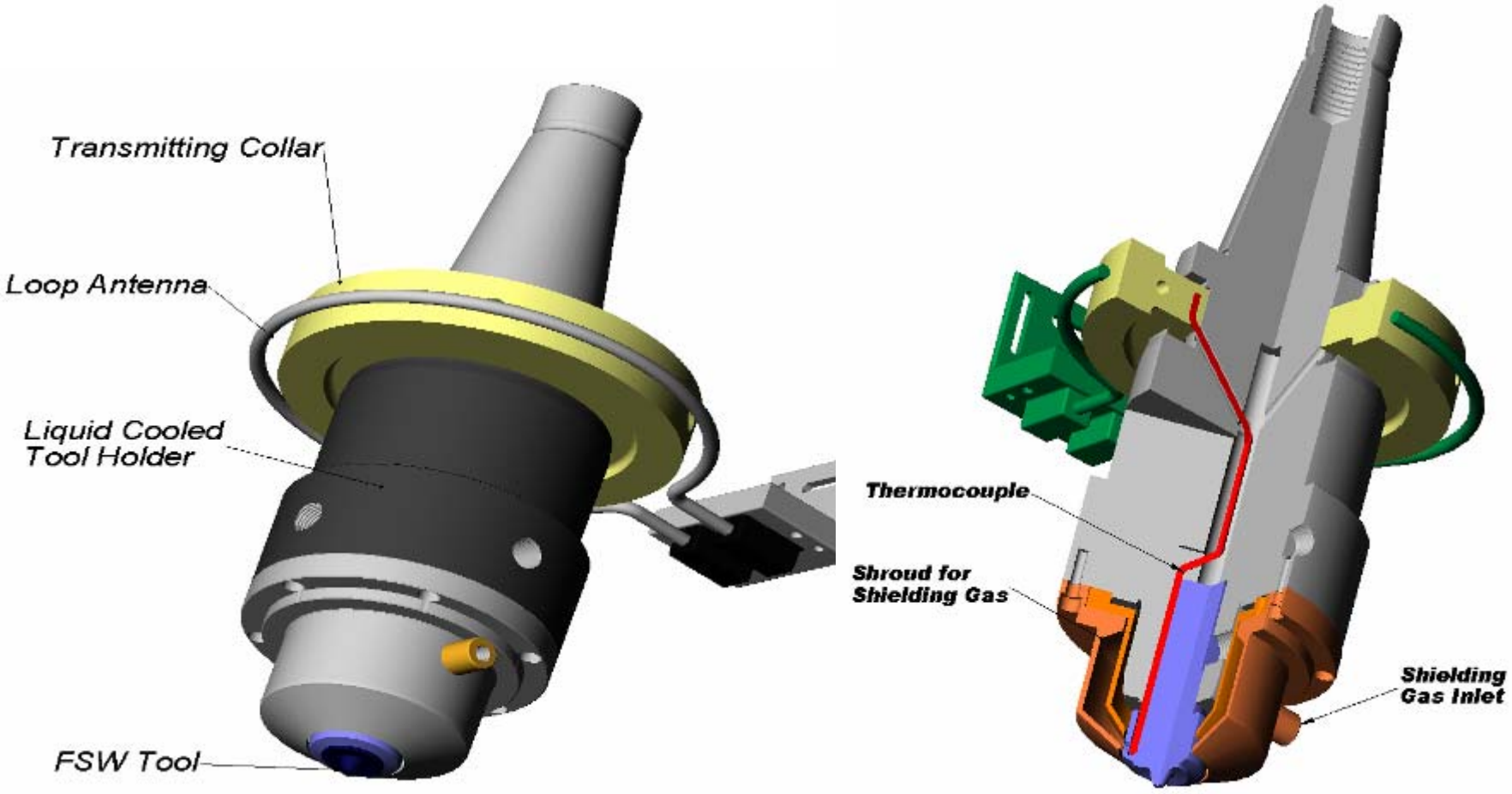


Tool Layout

- Locking collar to support PCBN
- Thermal barrier to slow heat transfer to shank

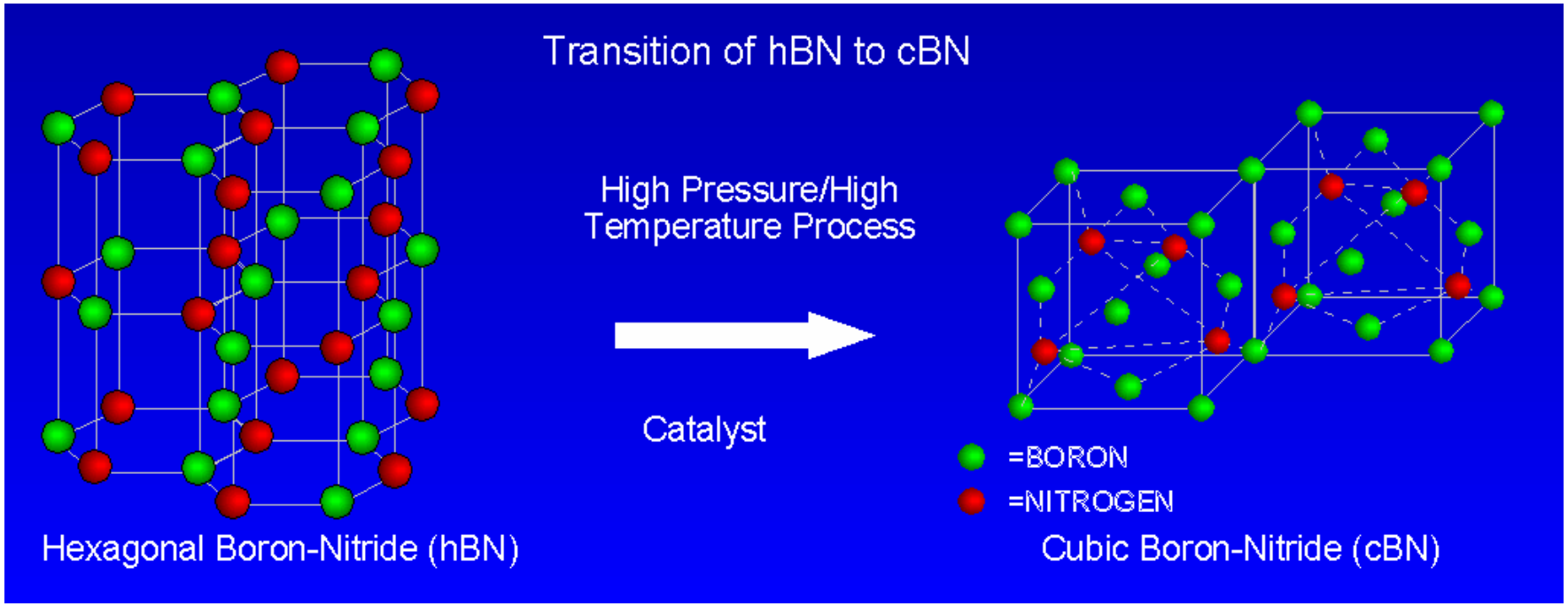


Tool Holder and Telemetry



Polycrystalline Cubic Boron Nitride (PCBN)

- PCBN is a Synthetic Super Abrasive Material
  - Created in HT-UHP presses (1450 C, 870 KSI)



Experimental Approach

- **Basic parameter study**
  - Parameters found which produced fully consolidated welds
  - Parameters are not optimized
- **Post weld analysis**
  - Tensile testing in accordance with ASTM E8
  - Transverse metallographic samples removed from each weld
  - 2507 Super Duplex microstructure examined using Orientation Imaging Microscopy (OIM)™

Materials

Alloy	Thickness
304 Stainless	0.250 in.
2507 Super Duplex	0.150 in.
Alloy 201	0.125 in.
Alloy 600	0.187 in.
Alloy 718	0.089 in.

- 40 CFH of Argon used in all welds

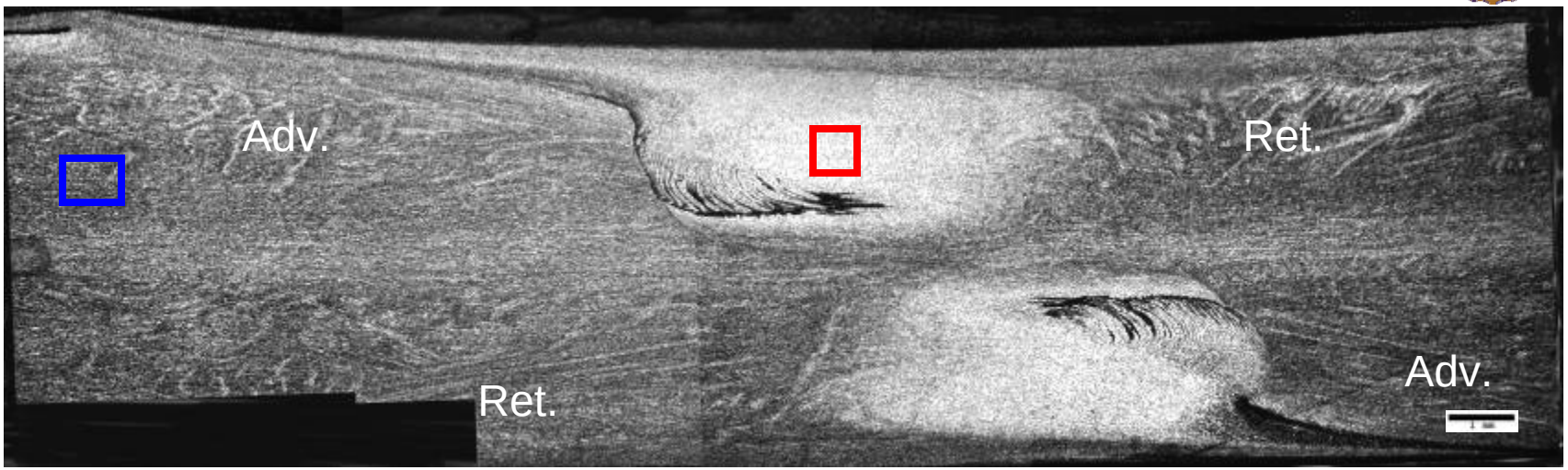
304 Stainless Steel

Welding Parameters:

Rotation: 400 rpm
Travel: 3 IPM
Load control: 9000 lbf

- Excellent weld appearance

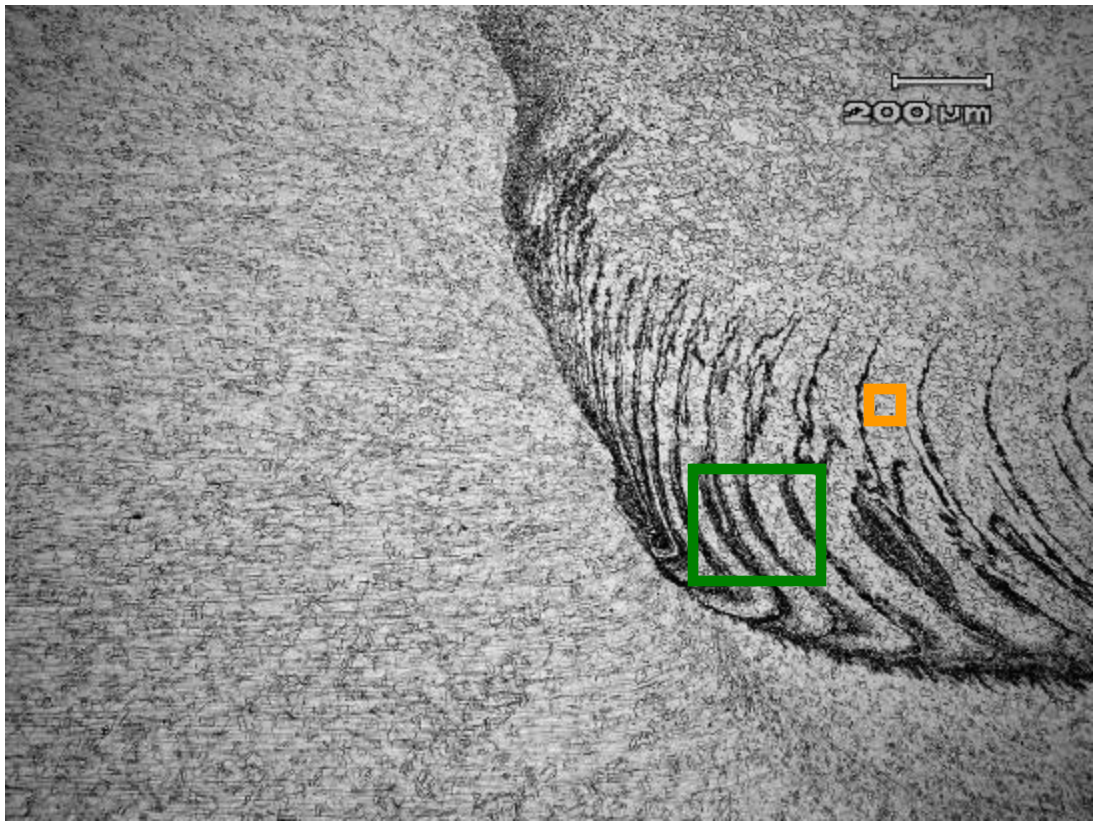
304 Stainless Steel

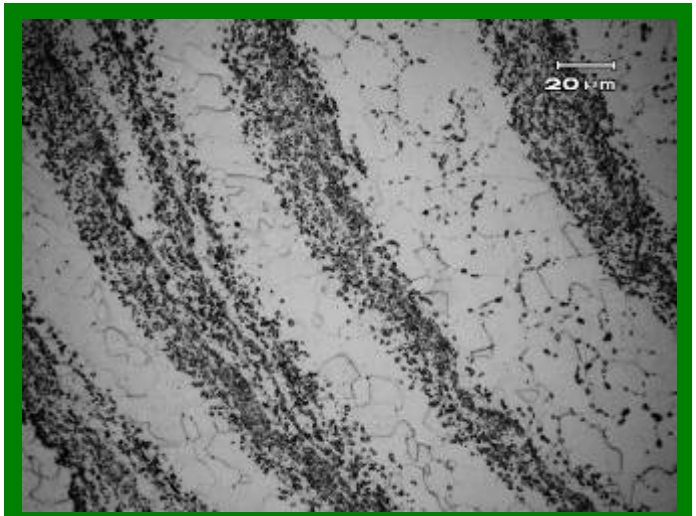


Base material *(500x)*

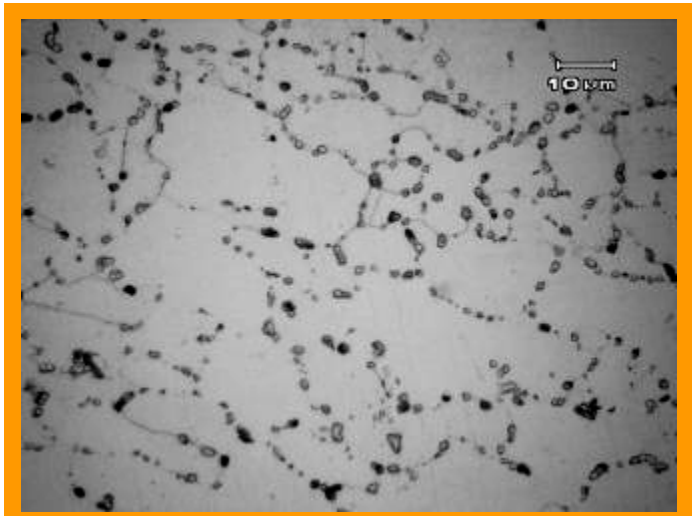
Center of DXZ *(500x)*

304 Stainless Steel





500x



1000x

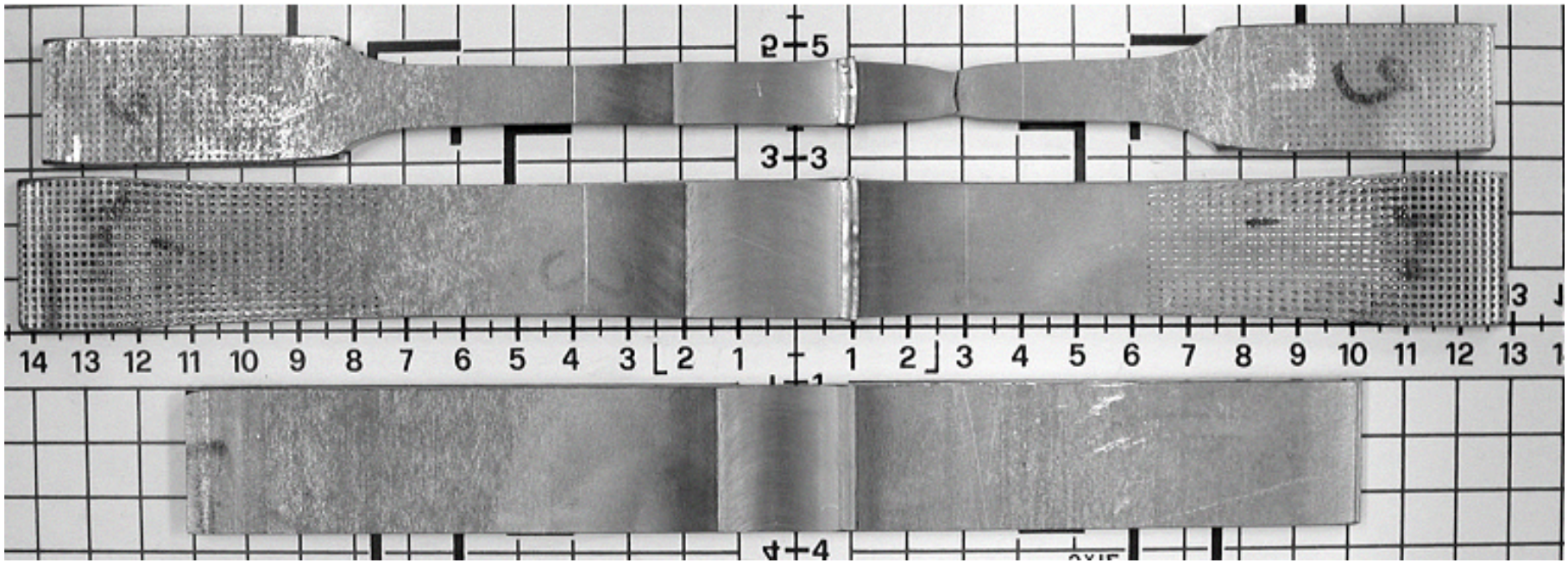
- **Sigma phase observed in bands**
  - Also observed at grain boundaries between bands

304 Stainless Steel

304 FSW Transverse Tensile Properties			
Sample	**Yield Strength 0.2 % offset KSI (MPa)**	**Ultimate Tensile Strength KSI (MPa)**	**Elongation %**
400 RPM, 3 IPM	***51 (352)***	***95 (655)***	***54***
Base Metal	***55 (379)***	***98 (675)***	***56***

- Tensile failures occurred in HAZ

304 Stainless Steel



- Reduction in area required for tensile specimens

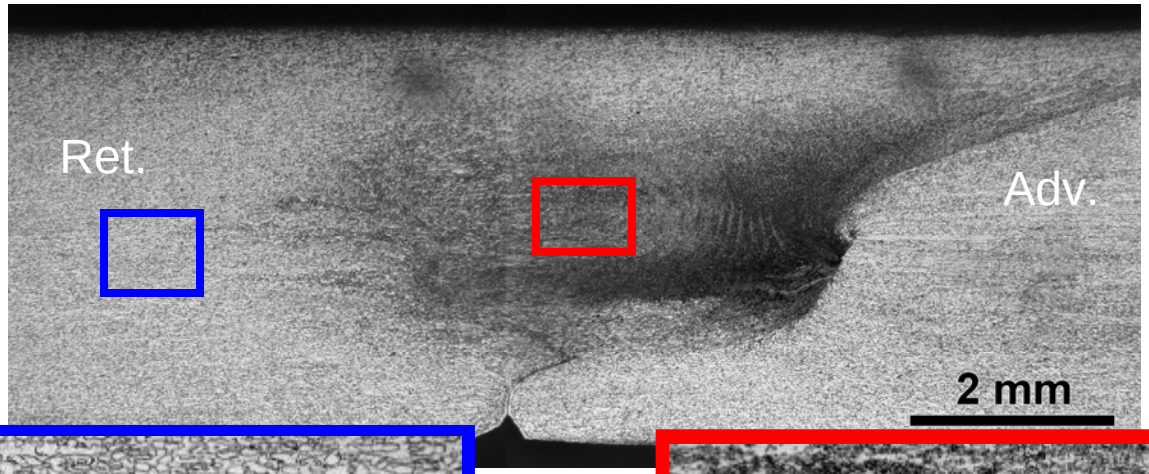
2507 Super Duplex Stainless Steel

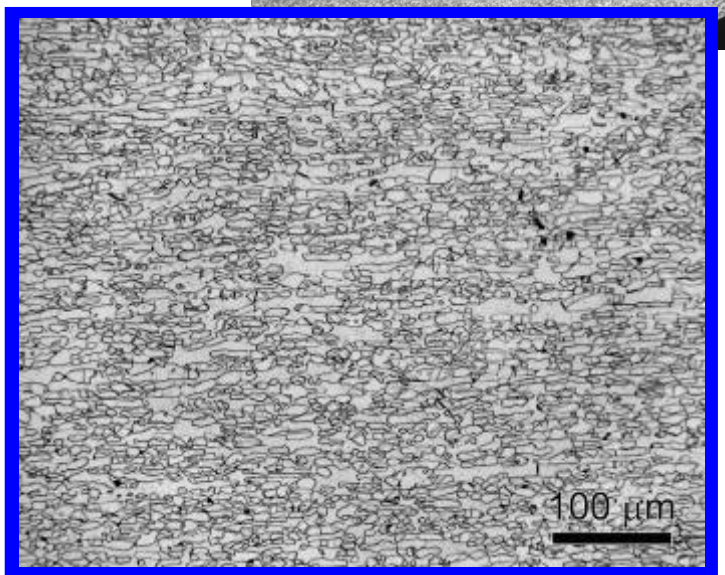
Welding Parameters:

Rotation: 450 rpm
Travel: 3.5 IPM
Load control: 7400 lbf

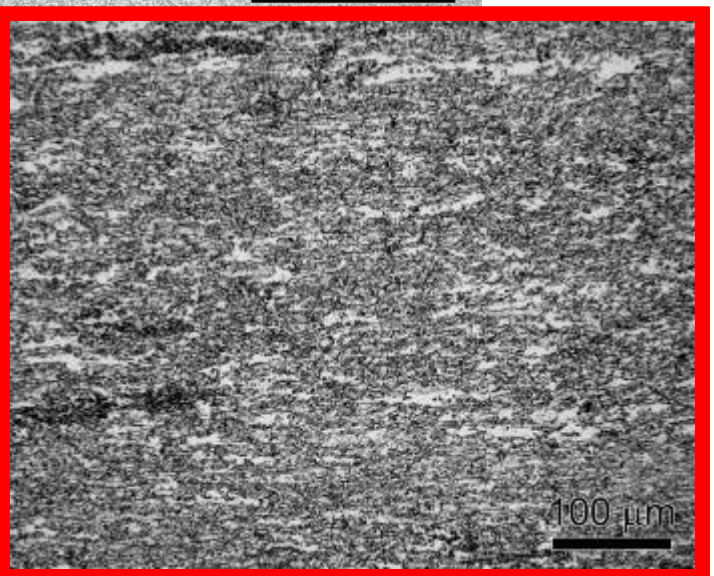
- Excellent weld appearance

2507 Super Duplex Stainless Steel





Base material *(200x)*

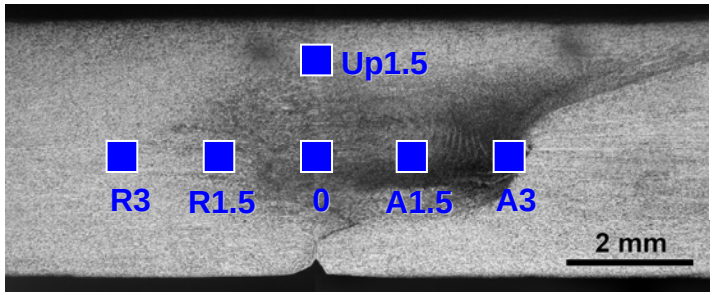


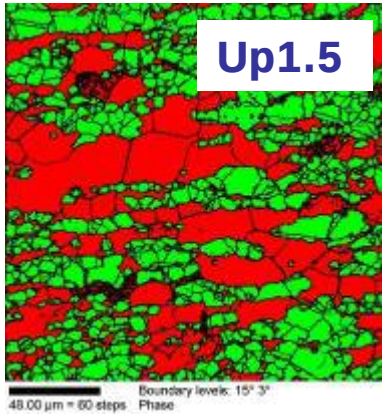
Center of DXZ *(200x)*

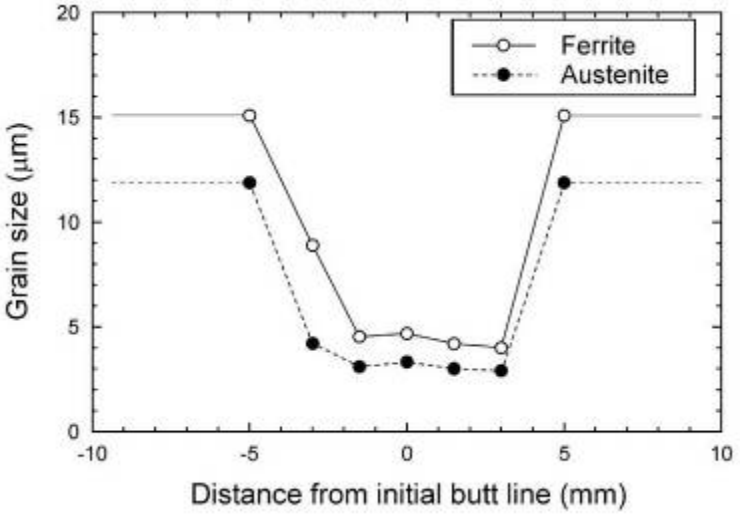
FSW produces fine microstructure in the stir zone.

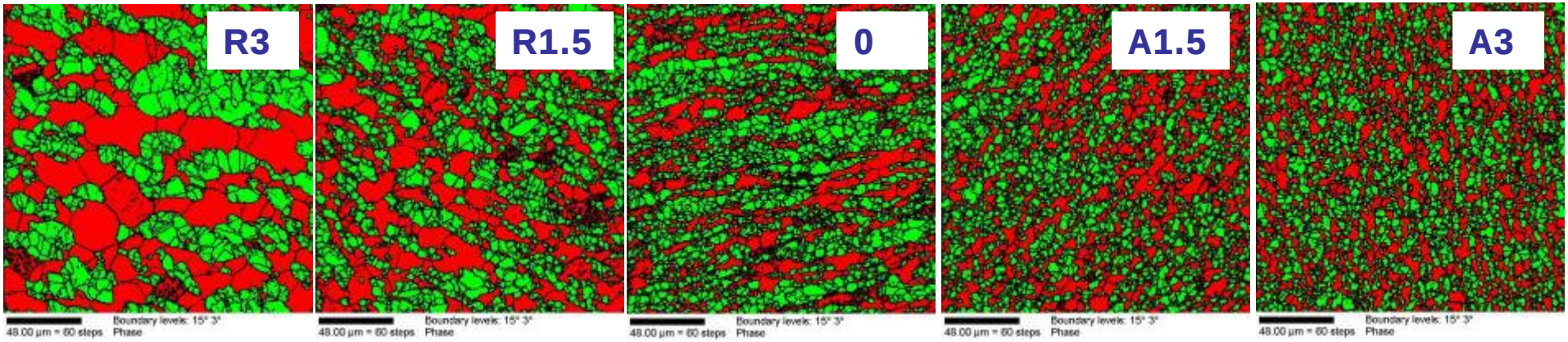
2507 Super Duplex Stainless Steel

Ferrite : Red
Austenite : Green









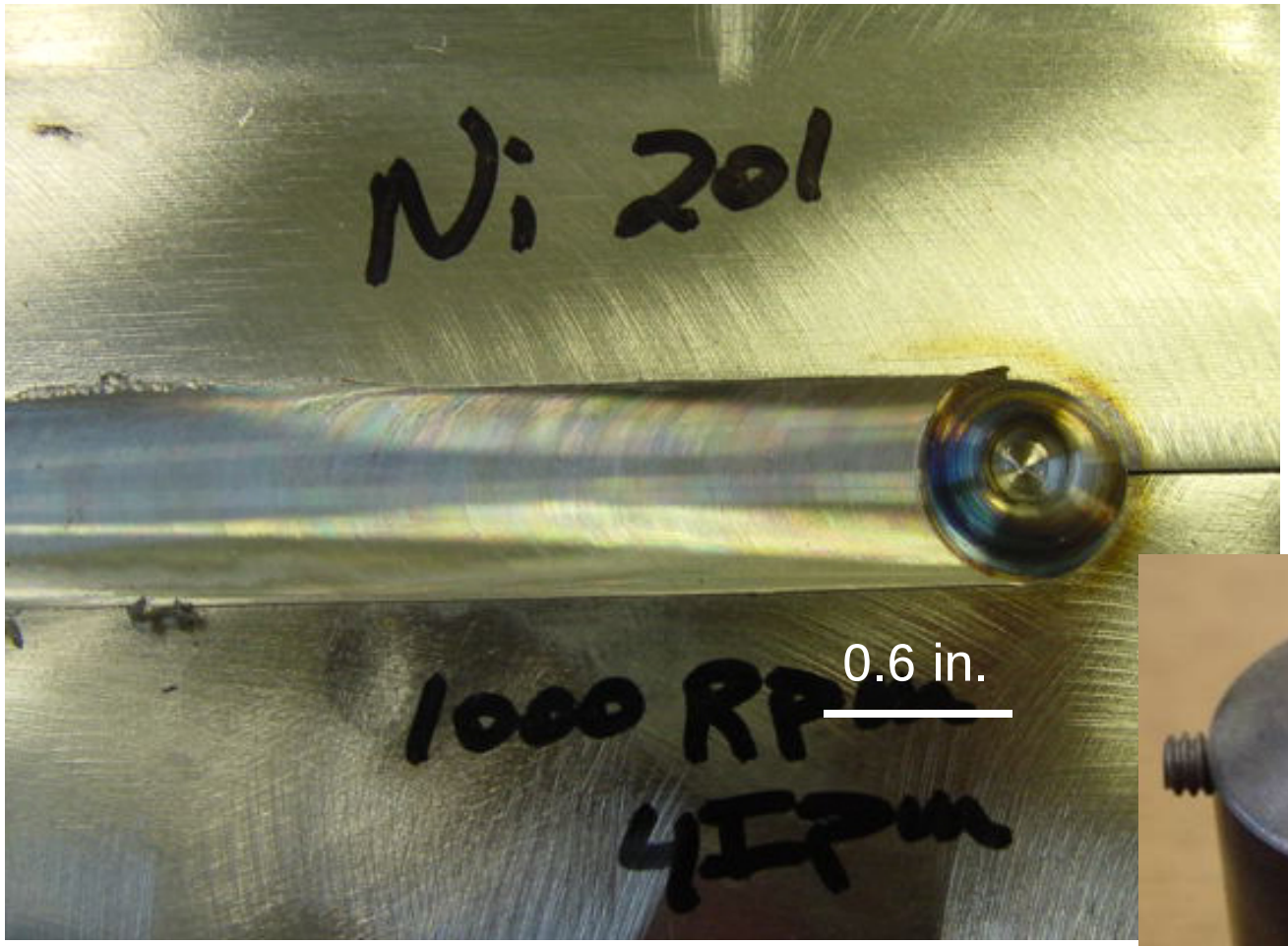
- Austenite phase exhibits smaller grain size than ferrite phase
- No evidence of sigma phase

2507 Super Duplex Stainless Steel

2507 FSW Transverse Tensile Properties			
Sample	**Yield Strength 0.2 % offset KSI (MPa)**	**Ultimate Tensile Strength KSI (MPa)**	**Elongation %**
450 RPM, 3.5 IPM	***110 (762)***	***123 (845)***	***19***
Base Metal	***102 (705)***	***128 (886)***	***30***

- Tensile failures occurred in DXZ

Alloy 201



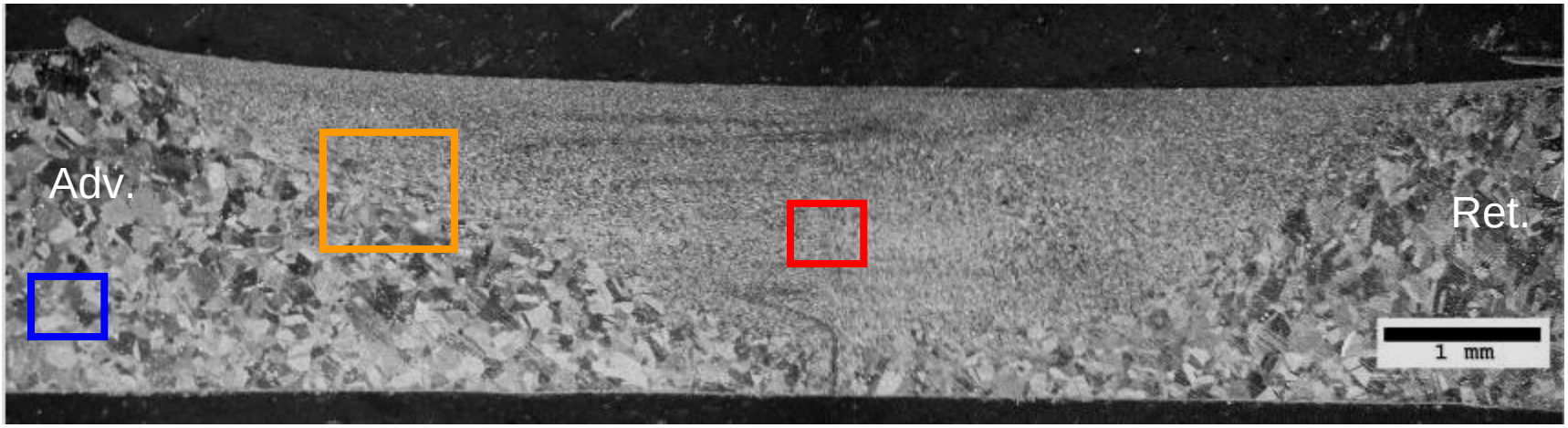
Welding Parameters:

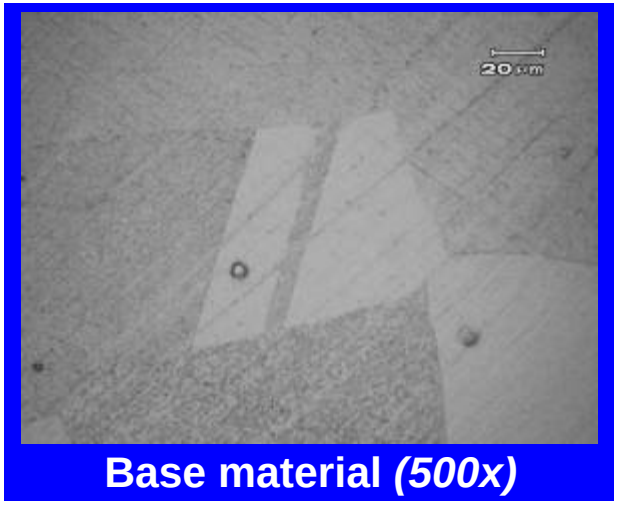
Rotation: 1000 rpm

Travel: 4 IPM

- *Tool previously used in alloy 718*

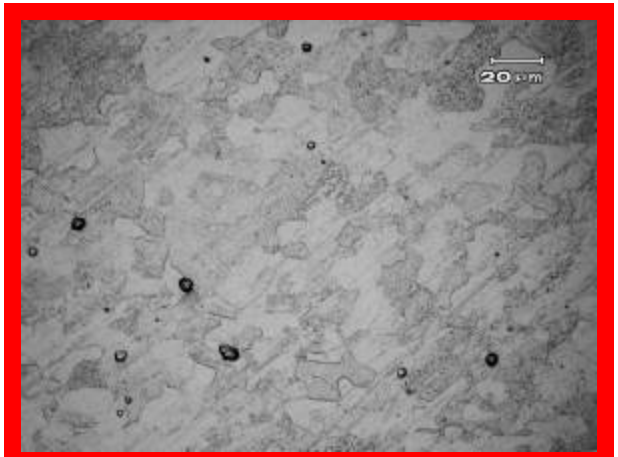
Alloy 201





Base material *(500x)*

TMAZ *(50x)*



Center of DXZ *(500x)*

Fine microstructure exhibited in DXZ

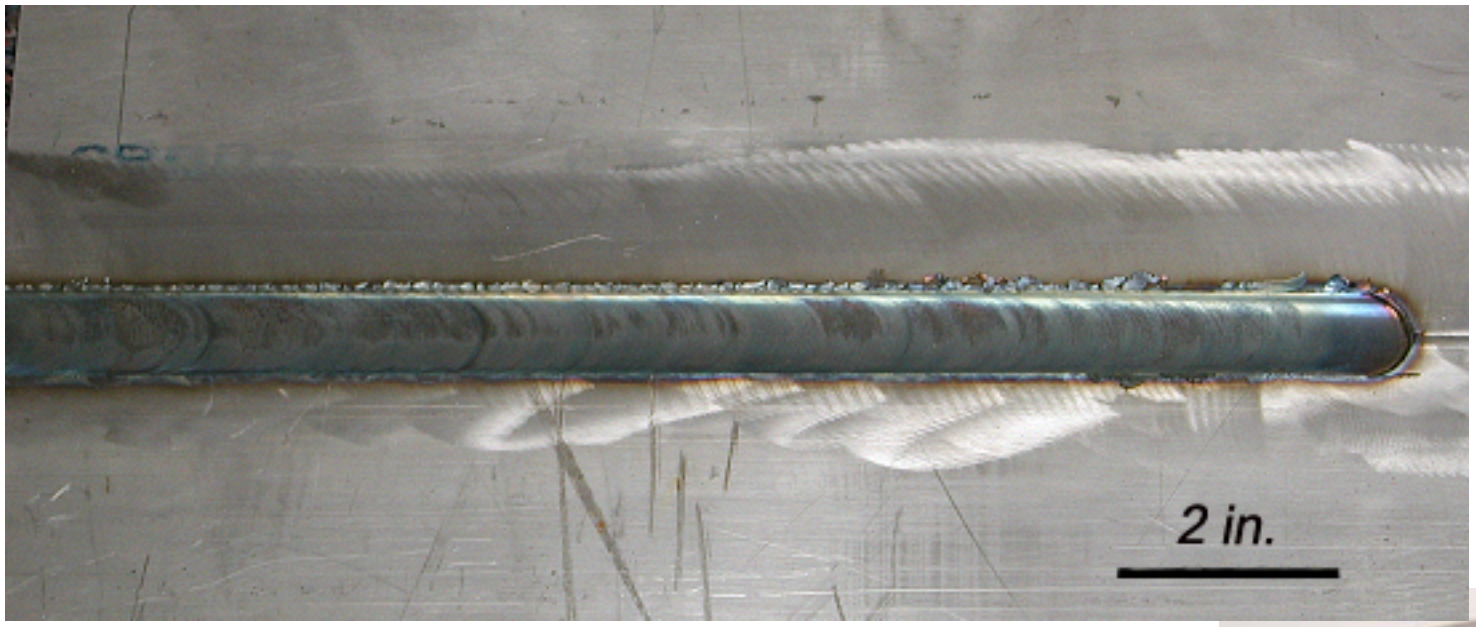
Alloy 201

Ni 201 FSW Transverse Tensile Properties			
Sample	**Yield Strength 0.2 % offset KSI (MPa)**	**Ultimate Tensile Strength KSI (MPa)**	**Elongation %**
1000 RPM, 4 IPM	***28 (193)***	***65 (448)***	***34***
Base Metal*	***15 (103)***	***59 (406)***	***50***

**** Nominal properties reported in literature***

- Tensile failures occurred in DXZ

Alloy 600

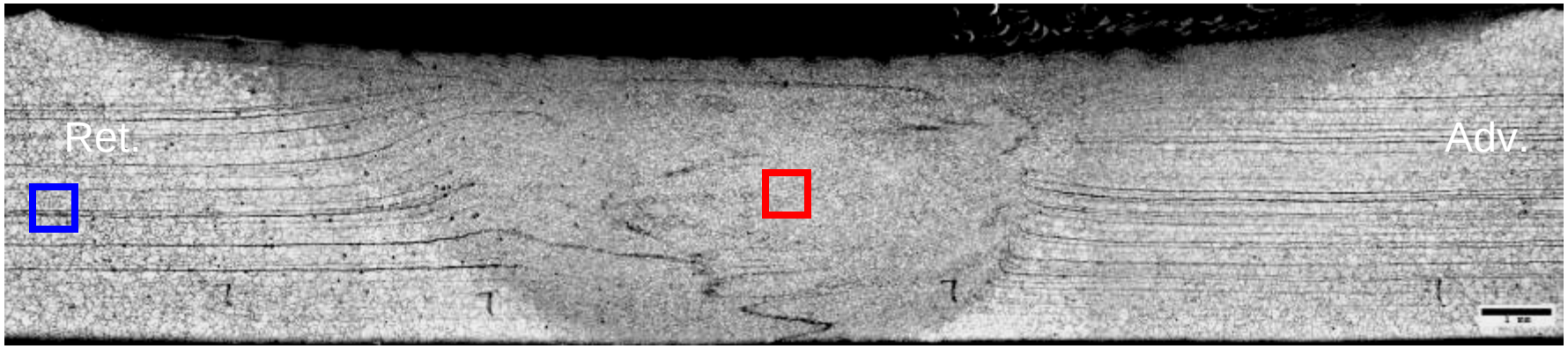


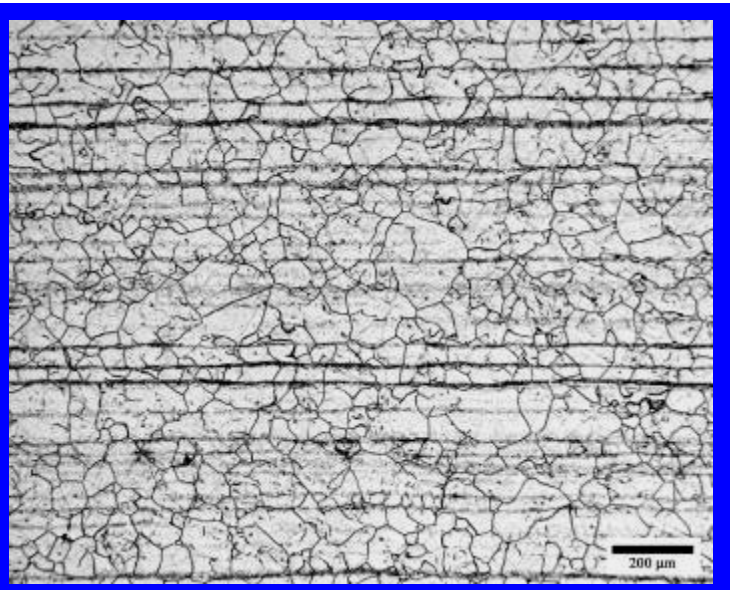
Welding Parameters:

Rotation: 450 rpm

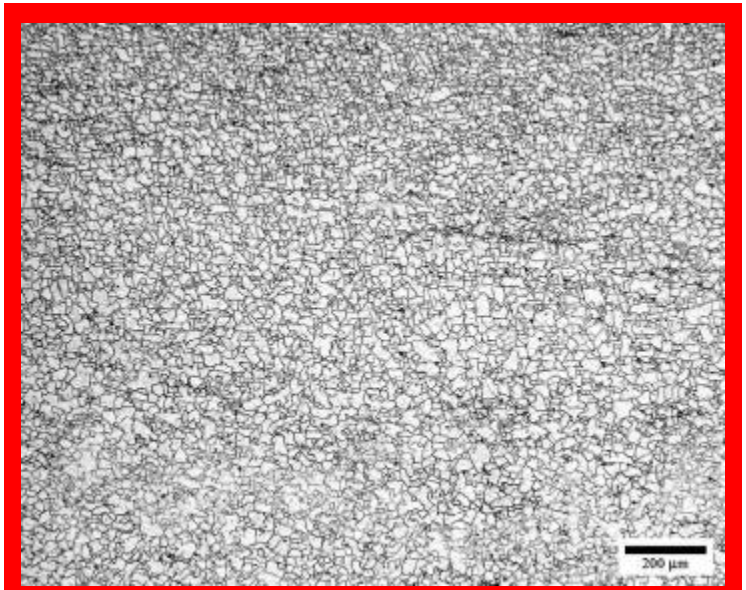
Travel: 2.25 IPM

Alloy 600





Base material *(100x)*



Center of Stir zone *(100x)*

Grain refinement exhibited in weld region

Alloy 600

Alloy 600 FSW Transverse Tensile Properties			
Sample	**Yield Strength 0.2 % offset KSI (MPa)**	**Ultimate Tensile Strength KSI (MPa)**	**Elongation %**
450RPM 2 ¼ IPM	***54 (374)***	***104 (719)***	***27***
Base Metal (annealed condition)	***38 (263)***	***92 (631)***	***50***

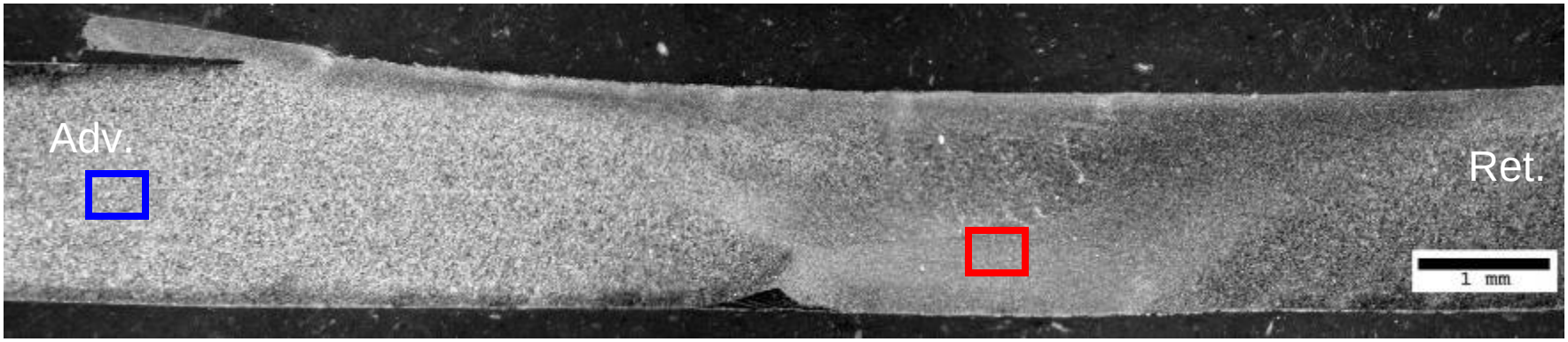
- Tensile failures occurred in the DXZ

Alloy 718

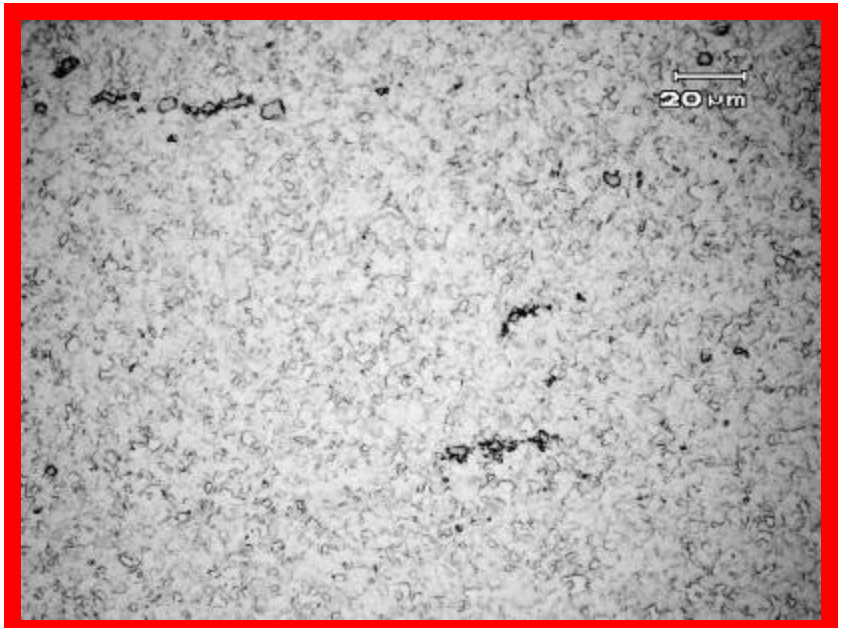
Welding Parameters:
Rotation: 500 rpm
Travel: 2 IPM

- Excellent weld appearance

Alloy 718



Base material *(500x)*



Center of DXZ *(500x)*

Grain refinement exhibited in weld region

Alloy 718

Alloy 718 FSW Transverse Tensile Properties			
Sample	**Yield Strength 0.2 % offset KSI (MPa)**	**Ultimate Tensile Strength KSI (MPa)**	**Elongation %**
500RPM , 2 IPM	***97 (668)***	***143 (986)***	***16***
Base Metal * (Annealed)	***67 (462)***	***130 (896)***	***41***
Base Metal * (precipitation hardened)	***170 (1172)***	***202 (1392)***	***22***

- Tensile failure in DXZ

**** Nominal properties reported in literature***

Review

- FSW exhibited feasibility in various different stainless steel and nickel base alloys
- Excellent mechanical properties
- Grain refinement exhibited in DXZ
  - Wrought microstructure

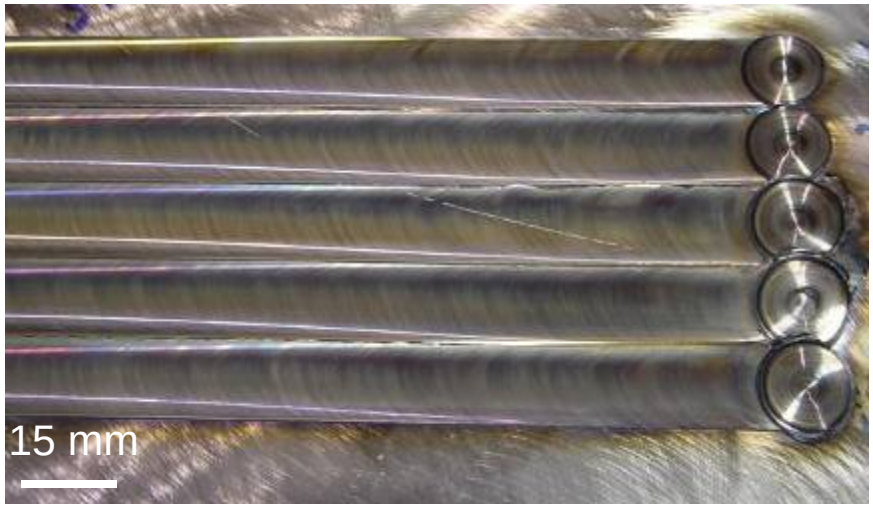
Tool Life

- Tool Life is always the big question
  - Life test under taken on 304 stainless steel and 1018 mild steel
  - 0.600 in. diameter shoulder with 0.085 in. length on pin
  - FSW machine capable of 40 in. of travel

Tool Life

100 feet of weld produced in 304 Stainless Steel

- 30 tool plunges

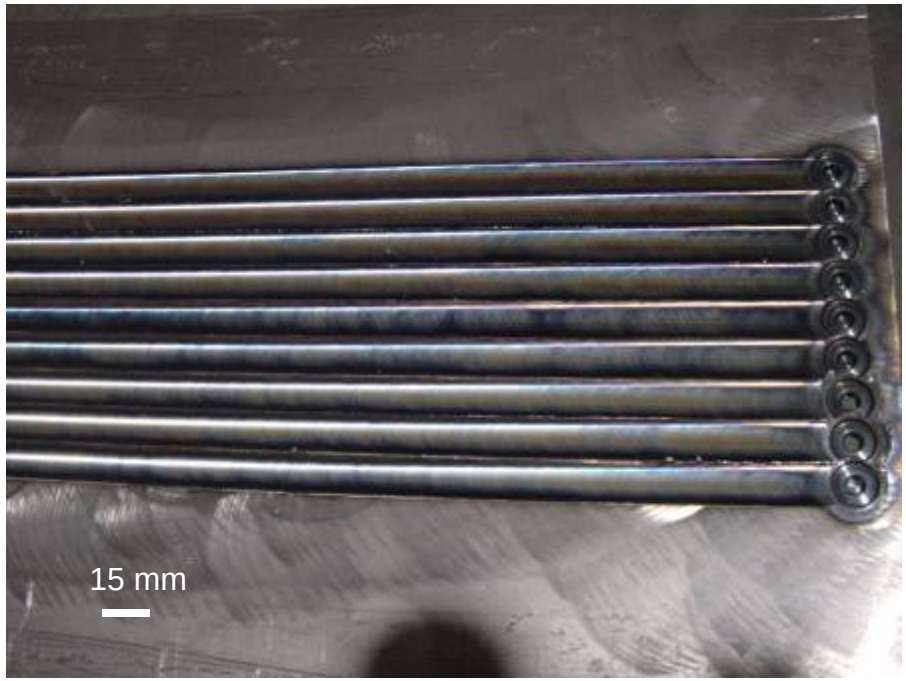


Bead on plate performed for life study

Tool Life

260 feet in 1018 mild steel

- Solved design issue in driving PCBN
- 78 tool plunges
- No visible wear
- Pin fractured at 262 feet



Bead on plate performed for life study

Tool Life

- PCBN grade development ongoing
  - Current grade being used is commercial machining grade
  - Ongoing program to develop FSW grades
  - Potential to tailor grades for different alloys

Summary

- PCBN proved to be viable FSW tool material for higher temperature materials
- Stainless steel and nickel base alloys can be successfully friction stir welded
  - Excellent weld quality and mechanical properties
  - Fine grain size in weld
- Tool life constantly improving