Investigating the effects of pin tool design on friction stir welded Ti-6Al-4V

H. A. Rubisoff, J. A. Querin, J. A. Schneider
Department of Mechanical Engineering
Mississippi State University

Friction stir welding (FSWing), a solid state joining technique, uses a non-consumable rotating pin tool to thermomechanically join materials. Heating of the weldment caused by friction and deformation is a function of the interaction between the pin tool and the work piece. Therefore, the geometry of the pin tool is in part responsible for the resulting microstructure and mechanical properties. In this study microwave sintered tungsten carbide (WC) pin tools with tapers and flats were used to FSW Ti-6Al-4V. Transverse sections of welds were mechanically tested, and the microstructure was characterized using optical microscopy (OM) and scanning election microscopy (SEM). X-ray diffraction (XRD) and electron back-scatter diffraction (EBSD) were used to characterize the texture within the welds produced from the different pin tool designs.

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H. Rubisoff, J. Querin, D. Magee, J. Schneider

Department of Mechanical Engineering

Mississippi State University

Mississippi State, MS 39762 USA

Overview

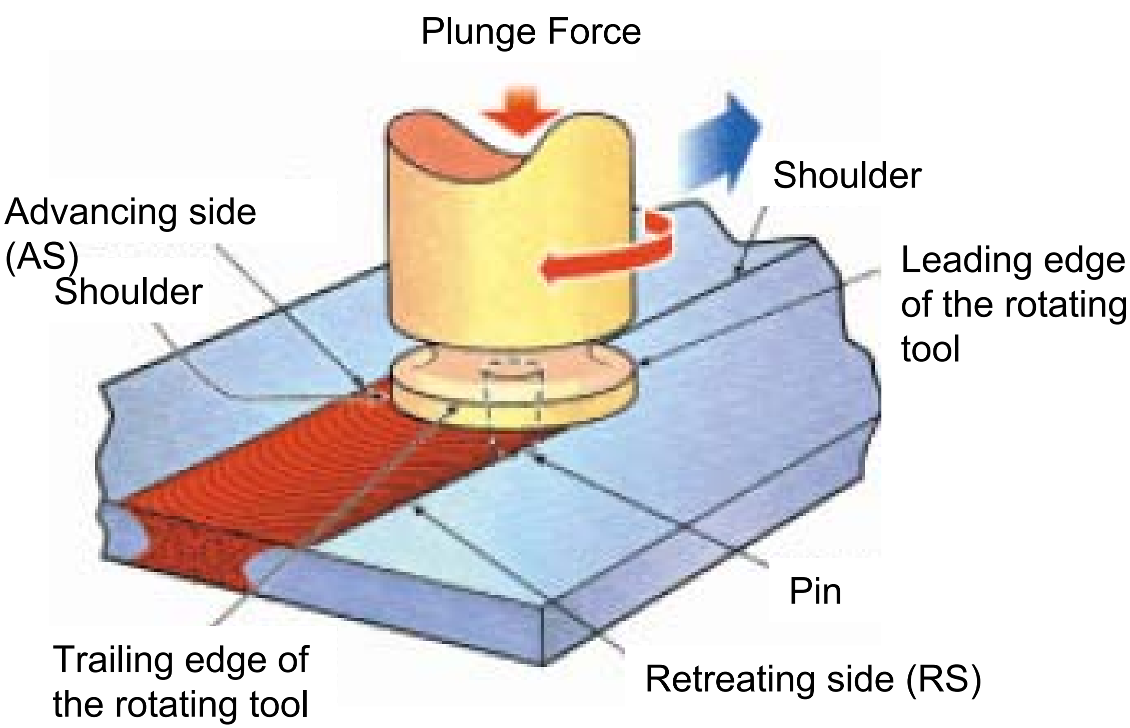
- Objective
- Ti-6Al-4V
- Weld Tools and Schedule
- Tensile Strength
- Microstructure
- Summary

Objective

- Investigate the microstructural response of Ti-6Al-4V following FSWing.
  - Response of 2 phase microstructure to deformation.
  - Effect of temperature range and gradients on low conductivity material.
  - Effect of phase transformation during FSWing.

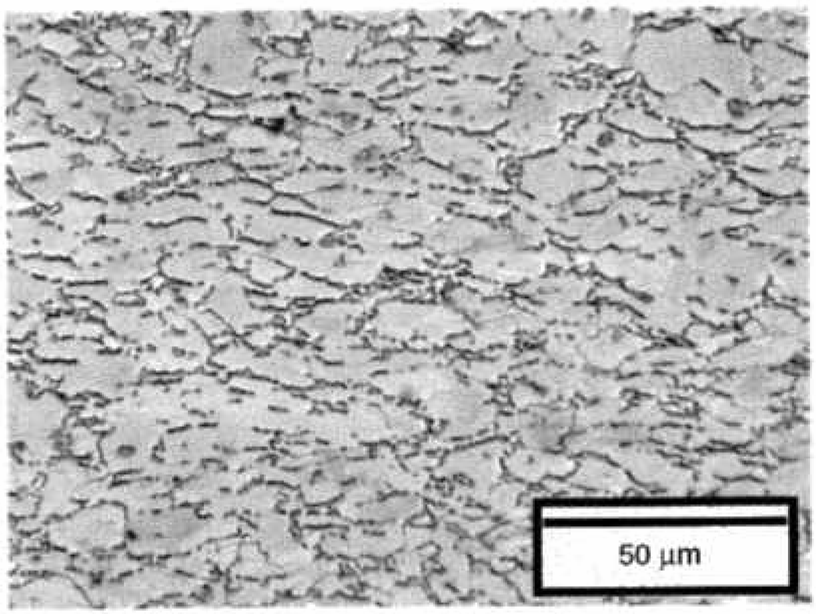
Friction Stir Welding

- Developed at The Welding Institute in 1991
- First used on aluminum alloys
- Solid-state process



Titanium 6Al - 4V

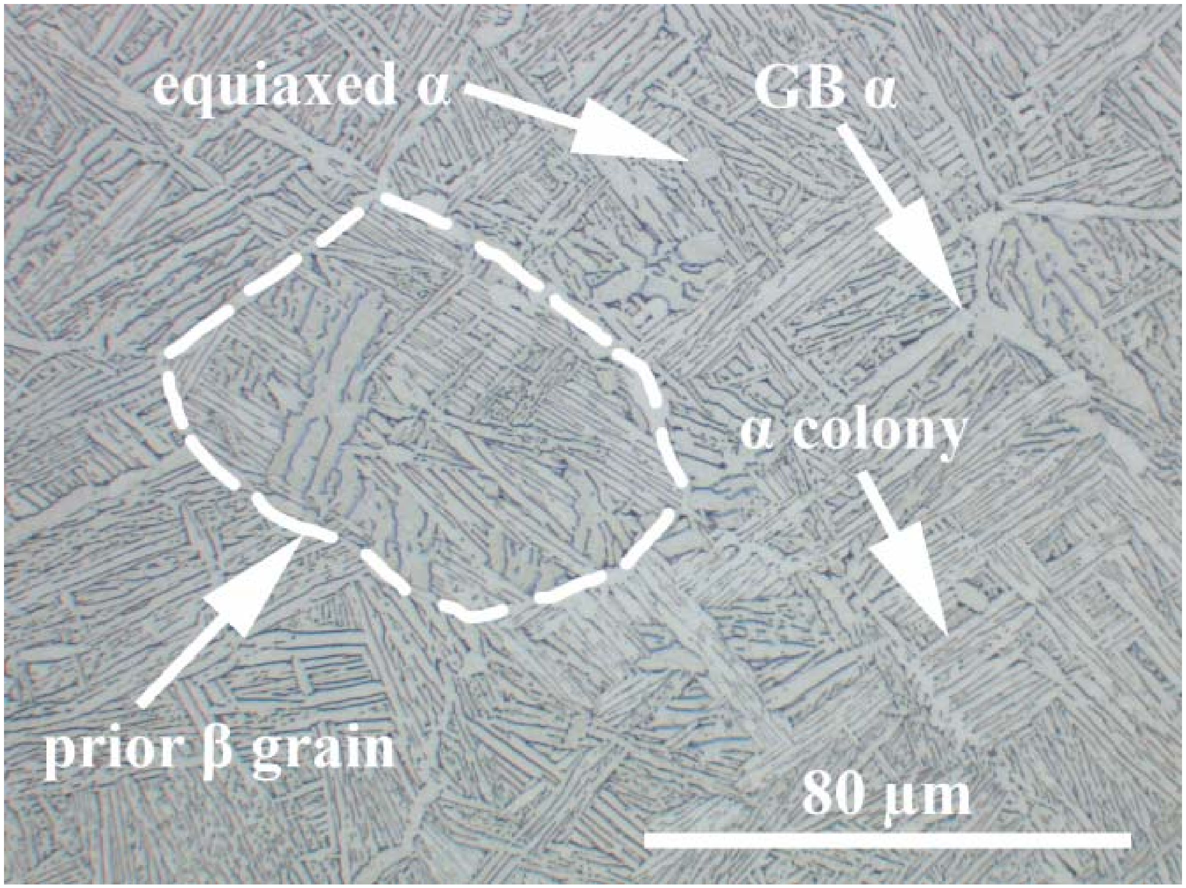
- Alpha- 12% beta alloy
- 6% Aluminum, 4% Vanadium
- Originally developed for the aircraft industry for high strength to weight properties



Micrograph of Ti-6Al-4V

Lienert, T.J. (2007). *Friction Stir Welding and Processing,* ASM International

Parent Material Microstructure is biomodal with prior β grains containing α colonies

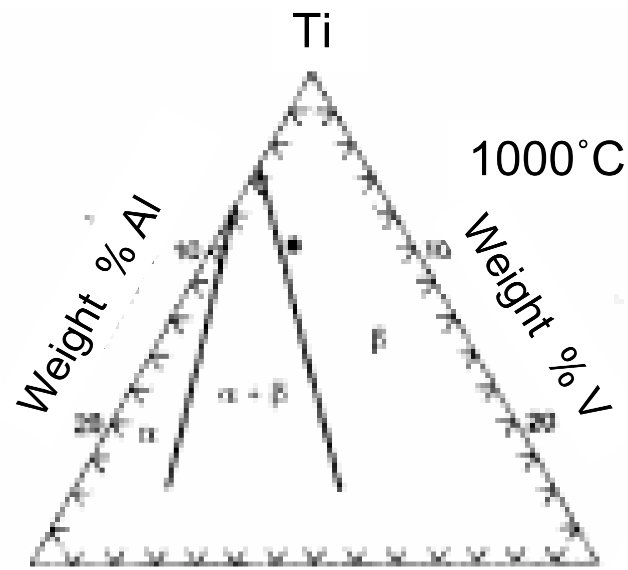


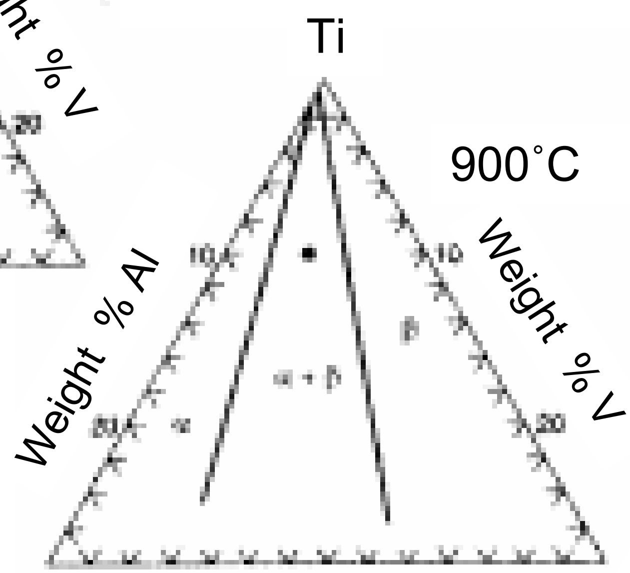
- Bimodal
  - equiaxed α (light regions)
  - colonies of alternating α+β laminate
- prior β grains: diameter 138 μm
- α colonies:17 μm
- α laths: width 1.4 μm
- equiaxed α: diameter 5 μm

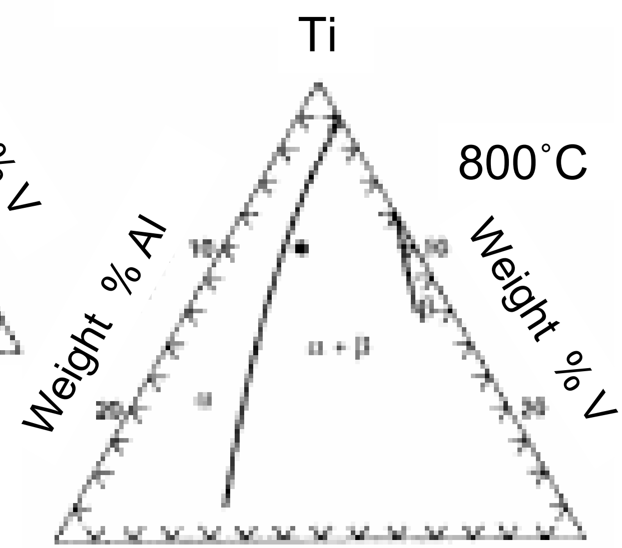
Expected temperature during FSW is about 60-90% of absolute melting temp

Expected FSW temp for Ti-6Al-4V = 850-1410˚C

β transus = 980˚C

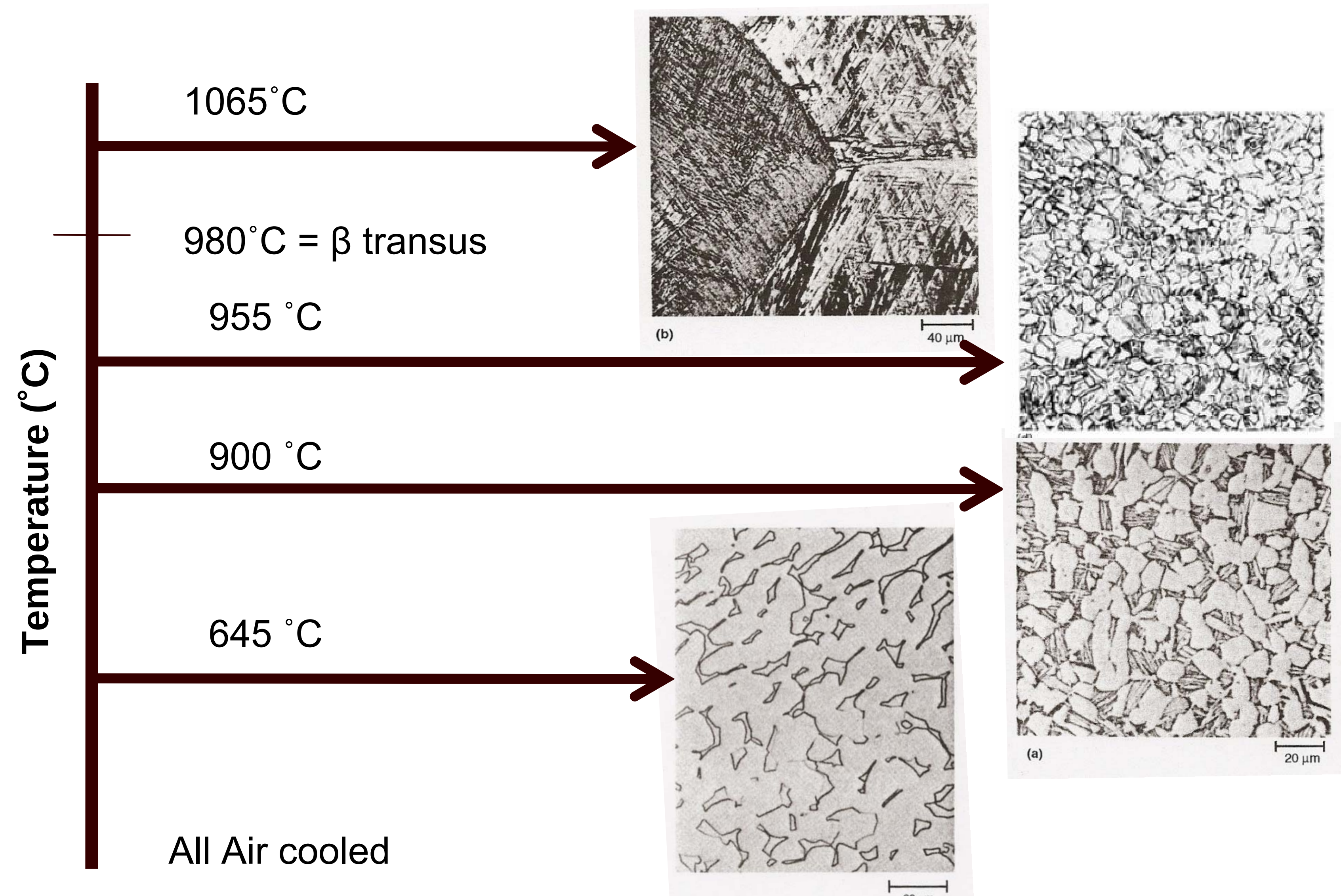






Lutjering, Gerd and James Williams. *Titanium*. Berlin: Springer- Verlag. 2003.

Variations in Ti-6Al-4V microstructure are a function of thermo-mechancial processing parameters



M. Donachie, Jr. *Titanium A technical guide*. Metals Parks, OH: ASM International. 1988.

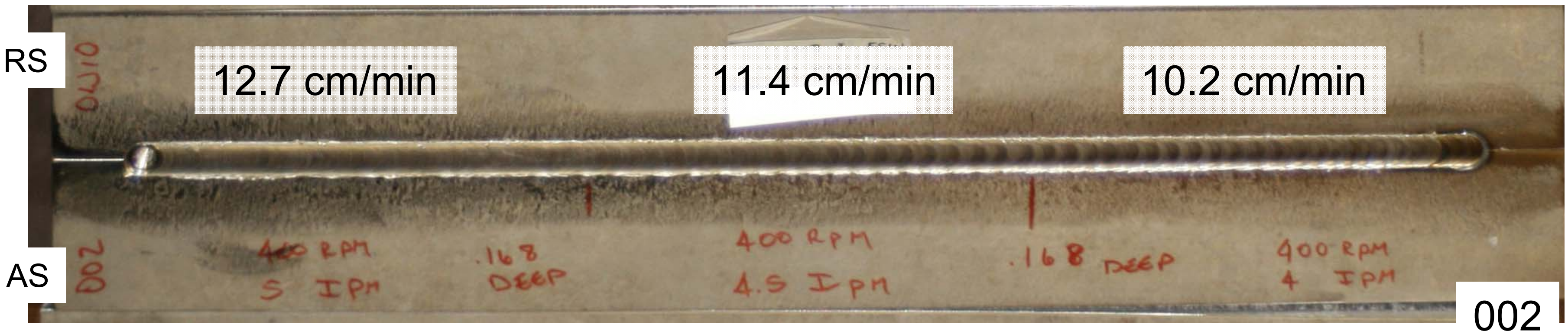
Weld Schedule

Ti-6Al-4V plates: 6.35 mm thk
Panels: 7.6 cm x 60.9 cm
Joint configuration: Butt Joint
Tool: Microwaved sintered WC
Weld control: Displacement

Weld ID	Taper angle (deg)	Spindle Speed (RPM)	Spindle Travel (cm/min)	Plunge depth (mm)
002	45	400	10.2 - 11.4 - 12.7	4.29
003	60	400	9.5 - 11.4 - 13.3	4.29

FSW in Ti-6Al-4V panel with 45° tapered tool

Panel Photo

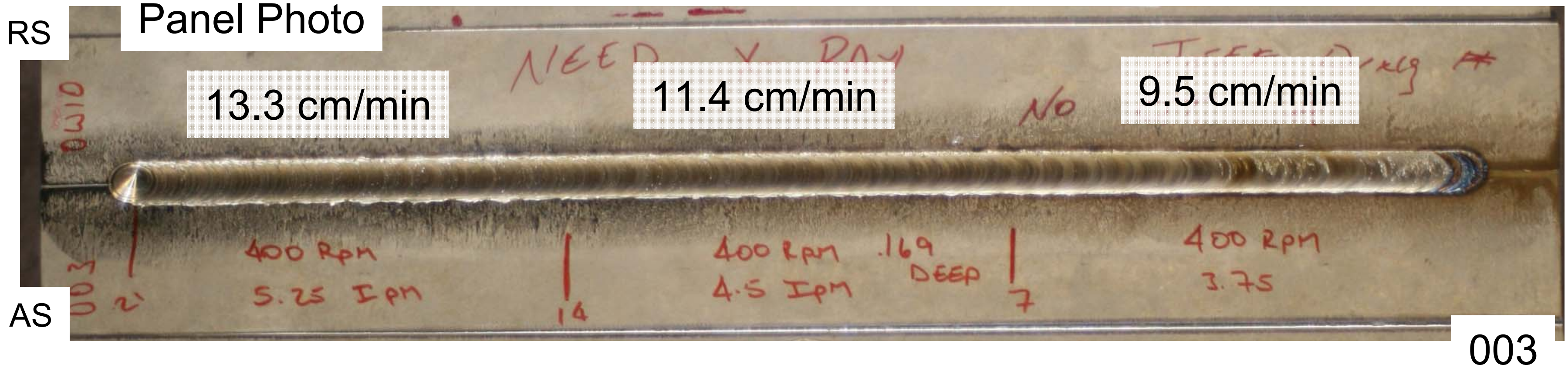


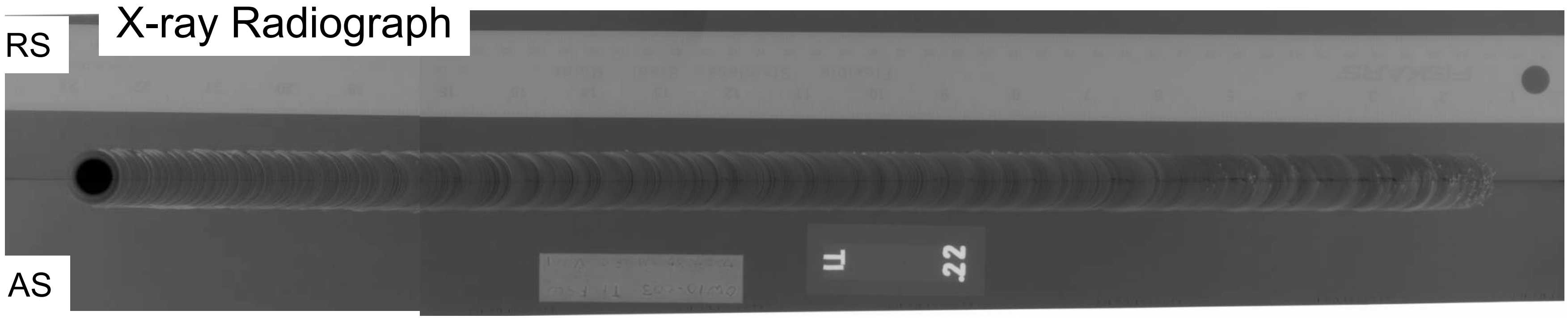
X-ray Radiograph

Weld direction

Indication of LOP due to 50% penetration of FSW

FSW in Ti-6Al-4V panel with 60º tapered tool

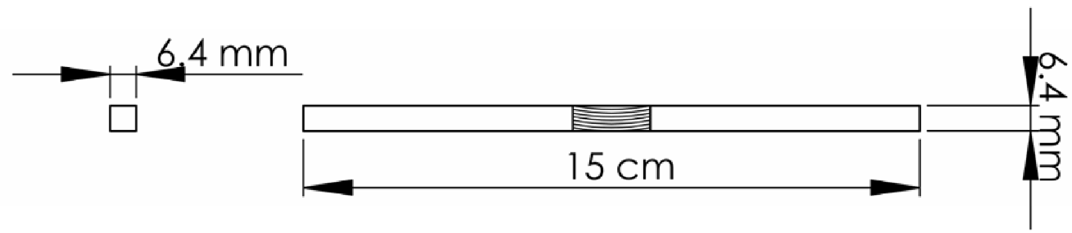


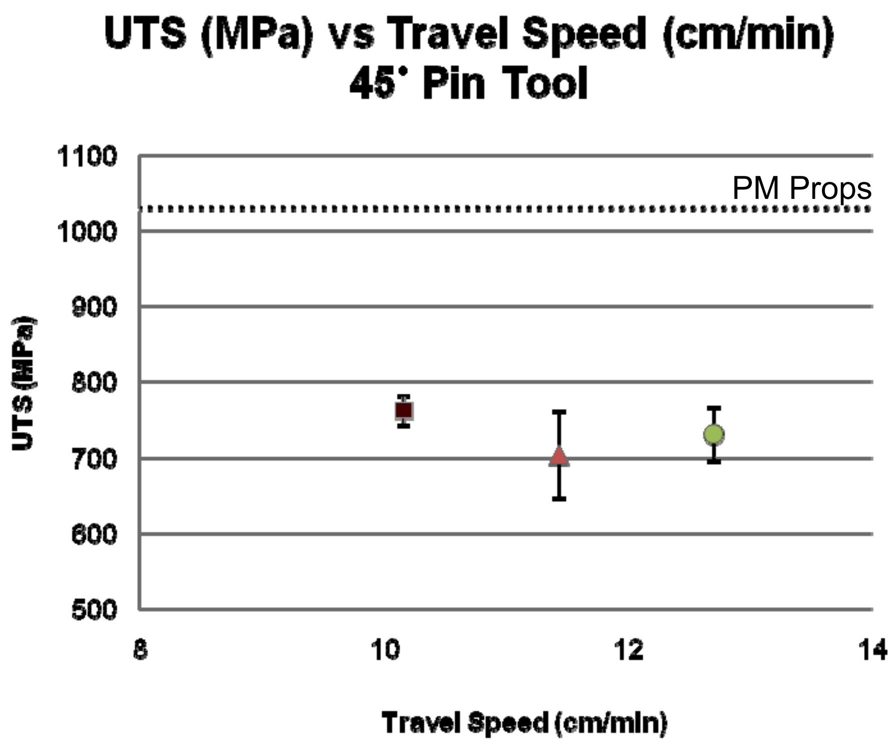


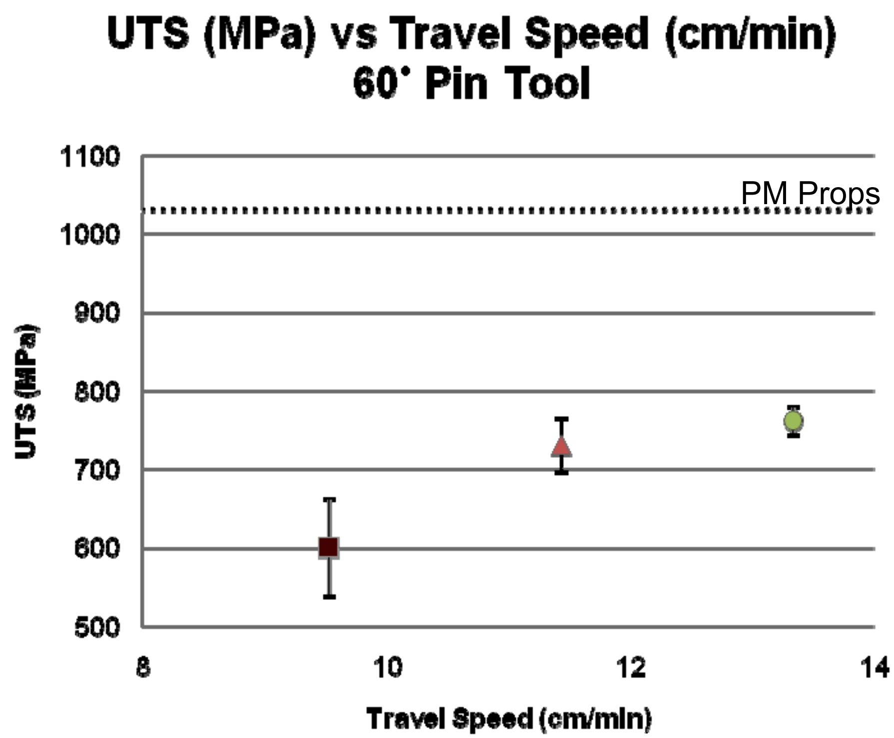
Weld direction

Indication of LOP due to 50% penetration of FSW

Effect of travel speed on tensile properties

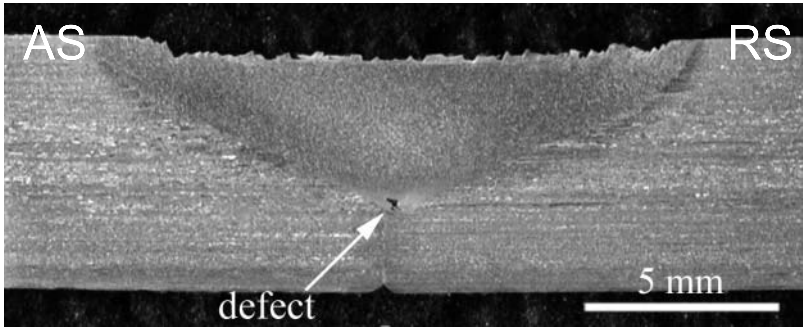




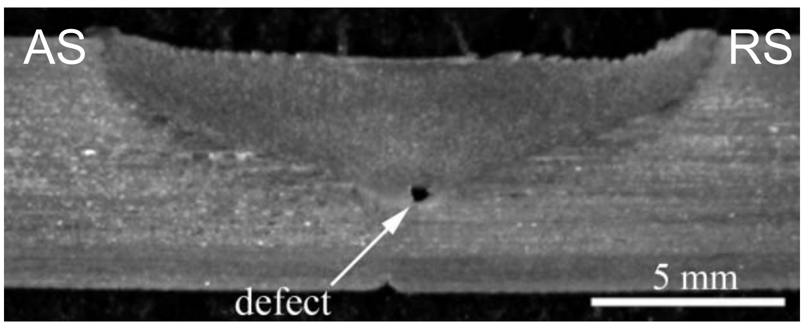


Wormhole defects were present in most welds

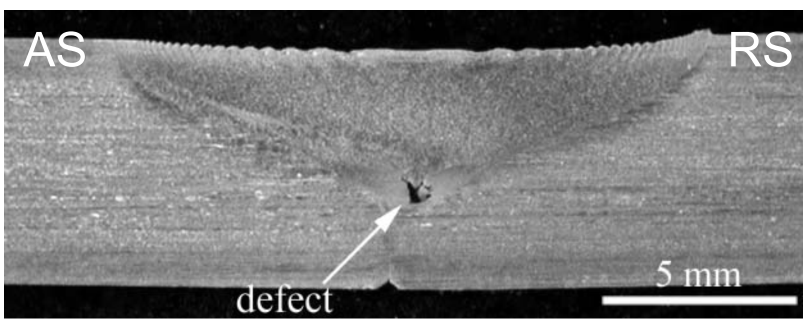
45˚ Pin tool



10.2 cm/min

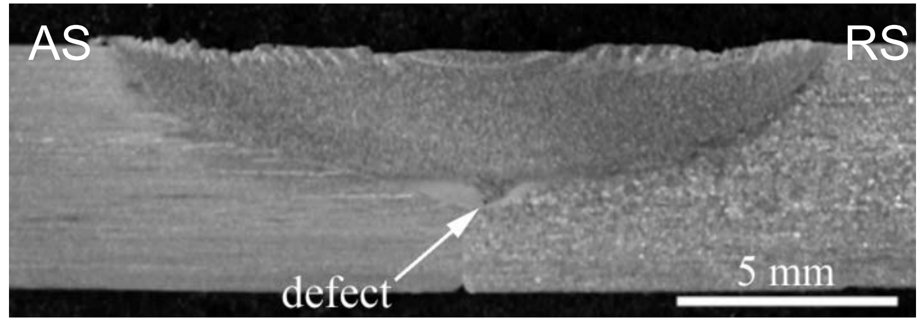


11.4 cm/min

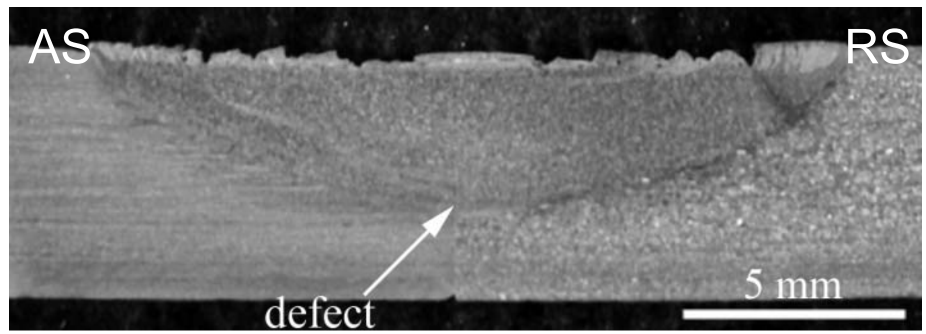


12.7 cm/min

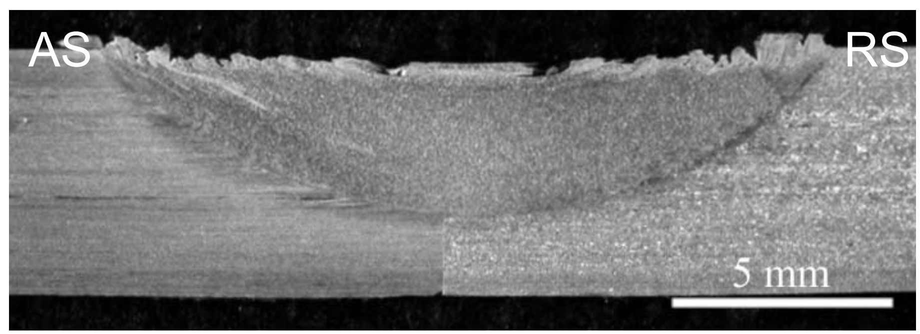
60˚ Pin tool



9.5 cm/min



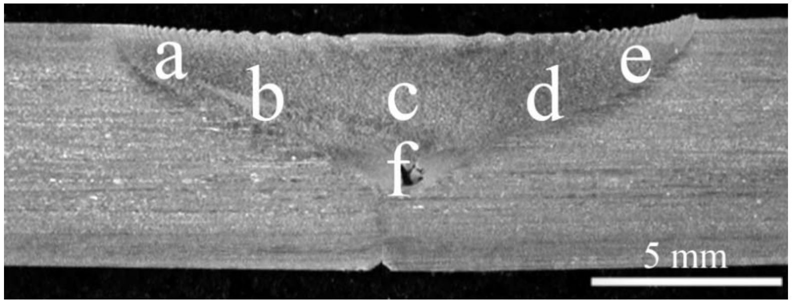
11.4 cm/min

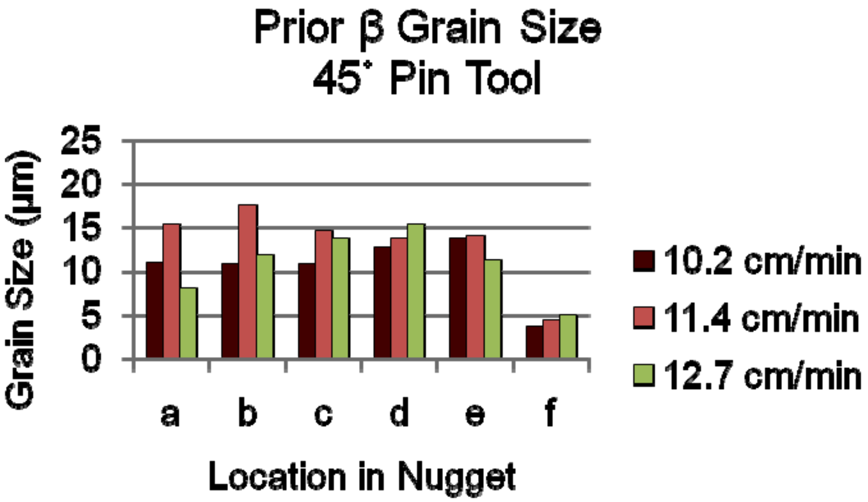


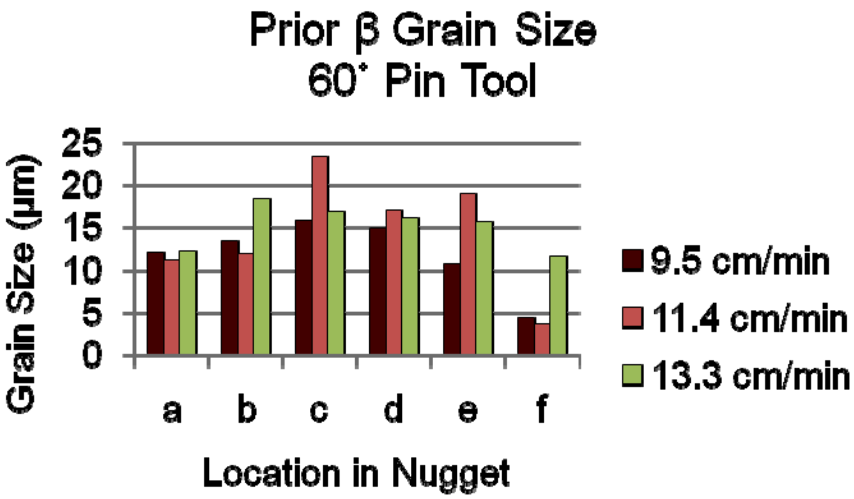
13.3 cm/min

Grain refinement observed in all welds

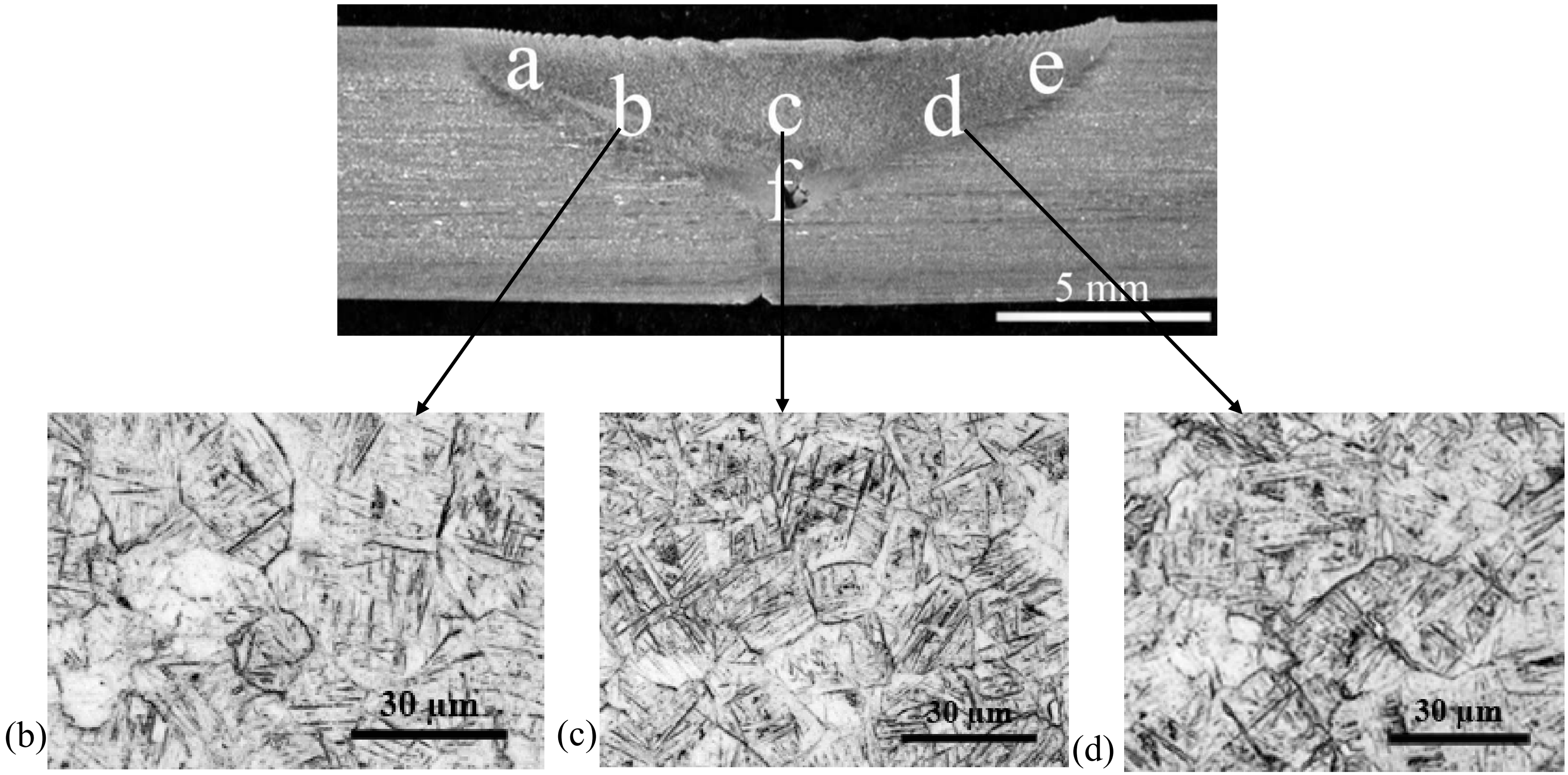
PM prior β grain size = 137 μm







Largest grains observed in mid-thickness

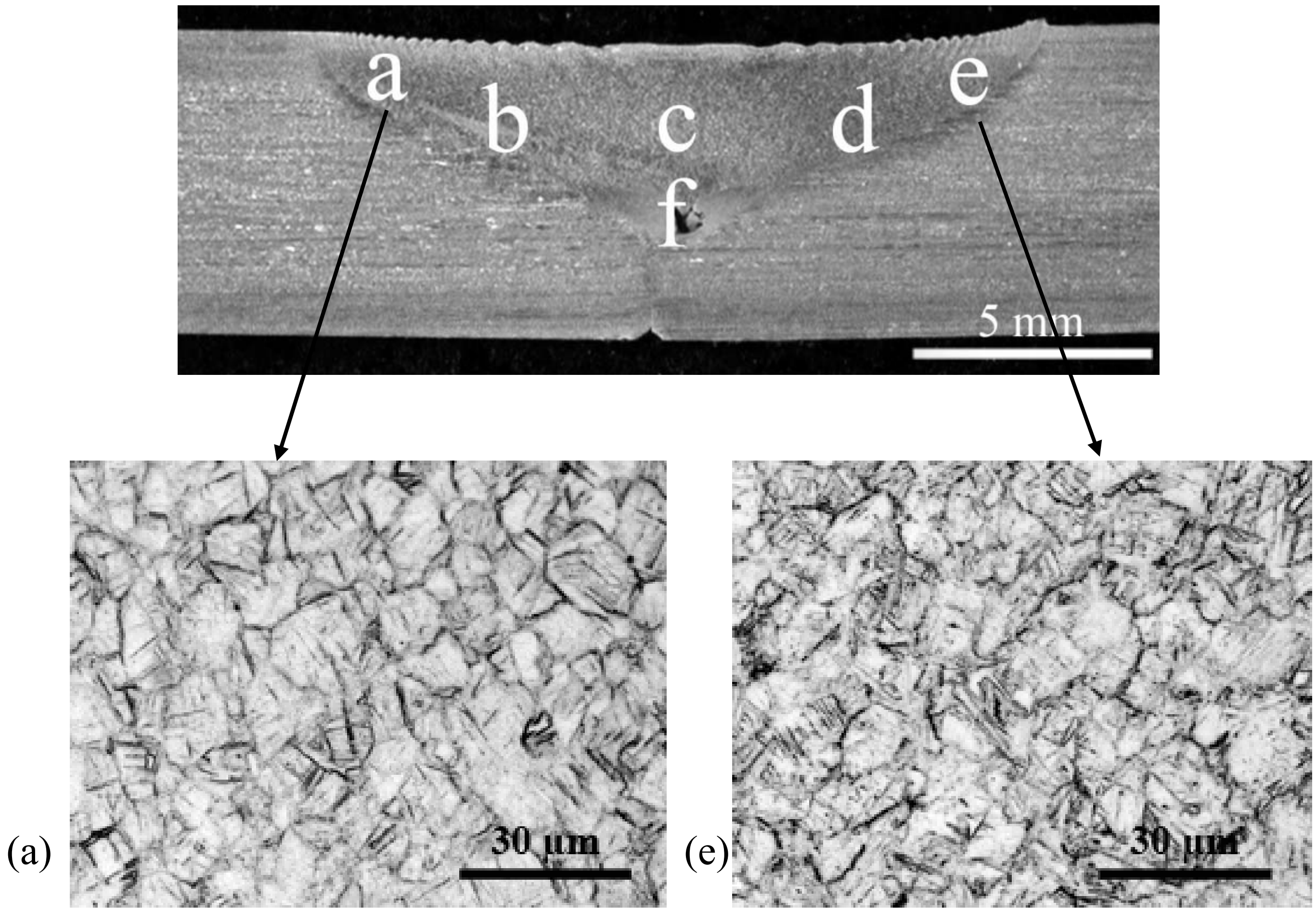


11-18 μm

11-23 μm

13-17 μm

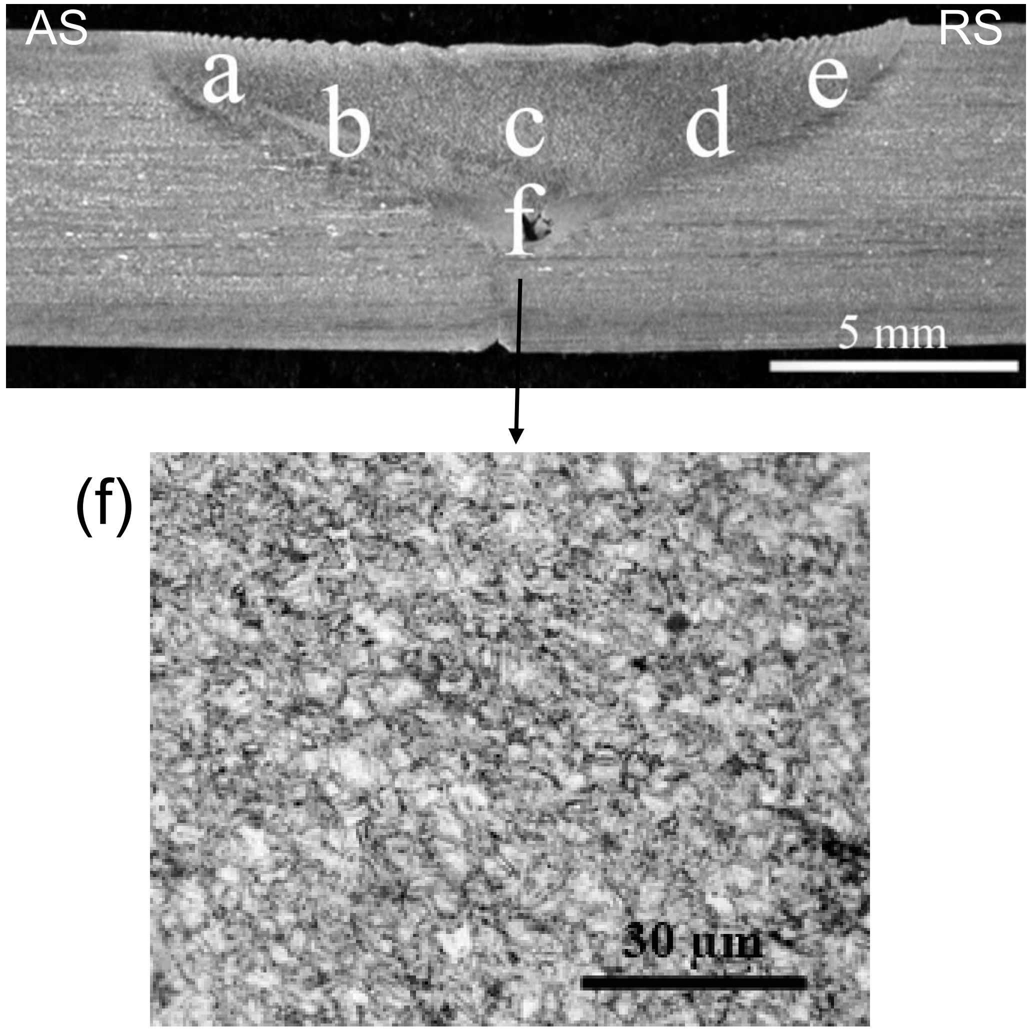
Small grains near shoulder



8-15 µm

11-19 µm

Smallest grains observed at the bottom



Grain size = 4-12 μm

Summary

- Within the range of parameters investigated, both weld tools created similar, refined microstructures within the stir zone.

- Based on the grain morphology, the β transus was exceeded in all welds.

- To reduce wormhole defects, a truncated design is recommended to increase the flow of the material around the tip of the pin tool.

Acknowledgements

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