Friction Stir Welding of Titanium Alloys

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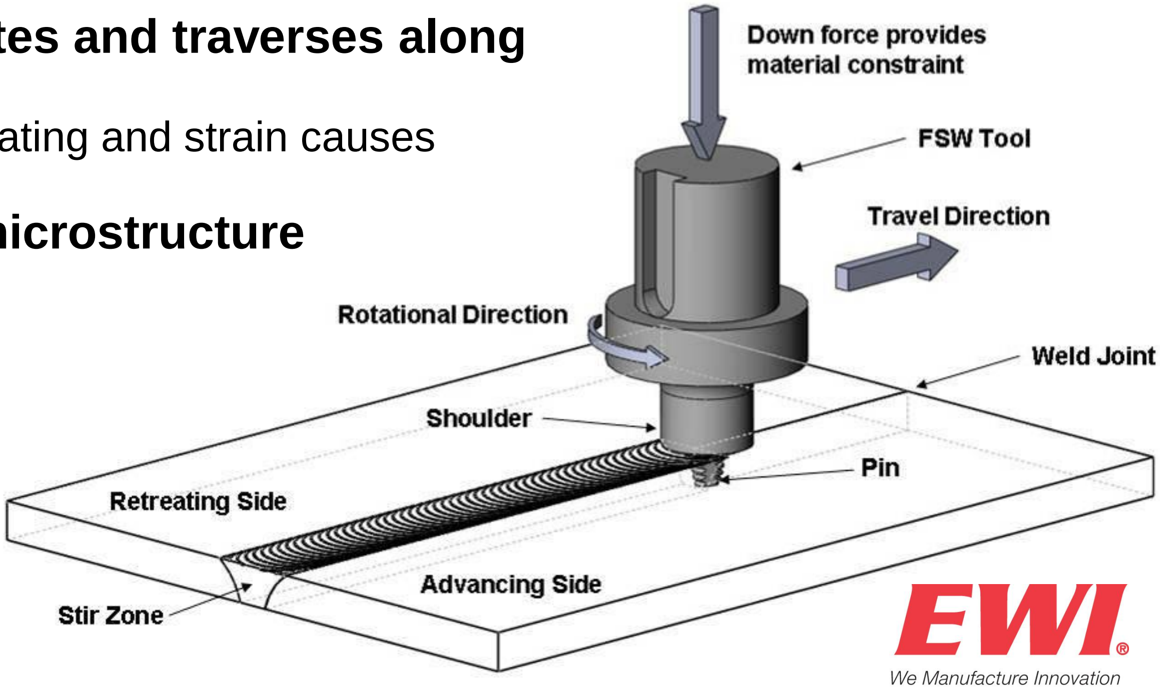
Background

- **Invented by TWI in 1991**
  - Wayne Thomas
- **Solid-state joining process**
  - No melting of the substrate
- **Capable of joining**
  - Aluminum, Magnesium, Copper, Steel, Titanium, Nickel, many more
- **Non-consumable tool rotates and traverses along a joint**
  - Combination of frictional heating and strain causes dynamic recrystallization
- **Creates a very fine grain microstructure**
  - Low distortion
  - Excellent weld properties



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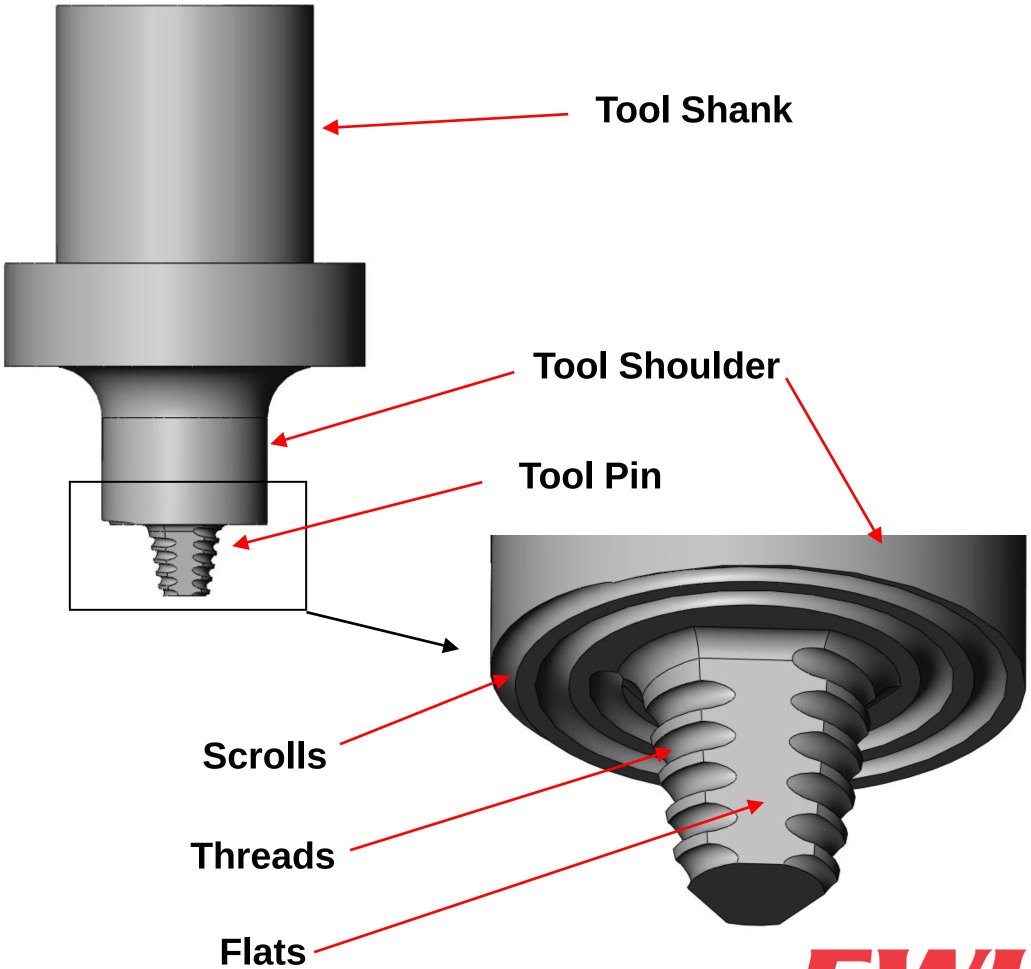
Friction Stir Welding

- **FSW Tool**
  - Shoulder: constrains material
  - Pin: stirs the joint interface
  - Flats, scrolls, threads: promote material movement
- **Fixturing**
  - Solid ridged fixturing is required to restrain the part to be welded
- **Critical parameters**
  - RPM: spindle rotation
  - Travel Speed: traverse speed



Typical Aluminum FSW Tool

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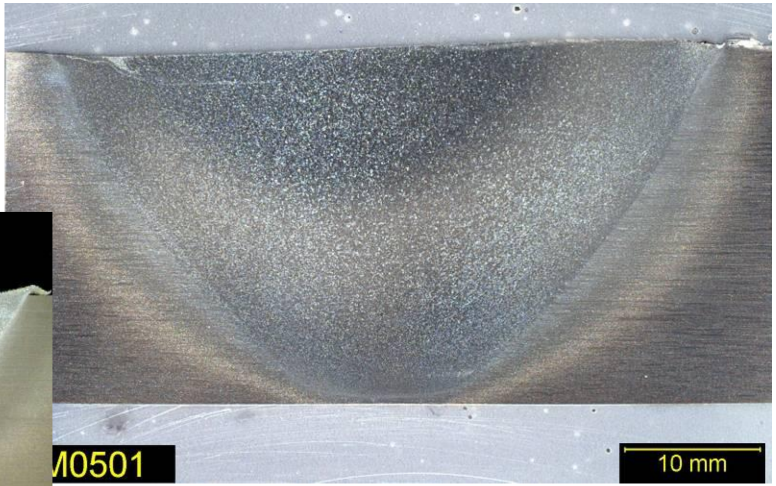
Why Friction Stir Welding

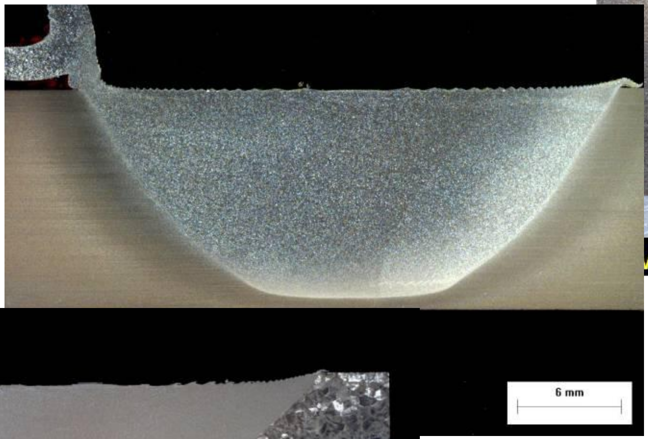
- **Advantages**
  - Solid-state process
    - Favorable weld properties
    - No melting
    - Low part distortion
  - Thick section single pass capability
    - Cost advantage in certain applications
  - Complex joint geometries possible (3-D)
  - Green process
    - Low energy consumption
    - Low consumable requirements
    - No hazardous fumes
- **Disadvantages**
  - Capital equipment cost
    - Often large and complex machines
    - Ridged fixturing requirements
  - Relatively slow travel speeds
  - Not easily portable
  - Process licensing fees
  - Limited code inclusion
    - Improving

FSW of Ti Capabilities

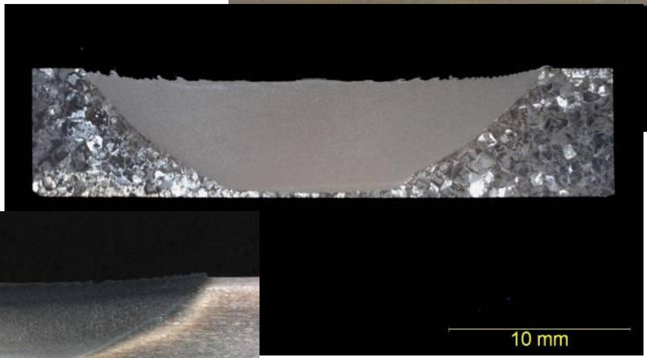
- **Single pass thickness**
  - 0.03-in to 1.0-in



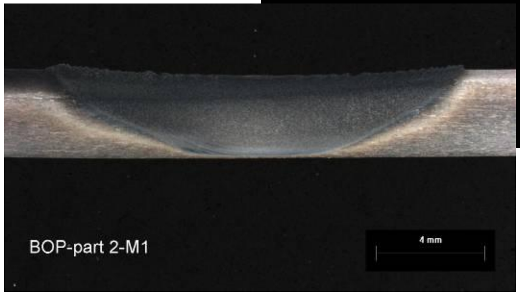
1.0-in Ti 6-4



0.5-in Ti 6-4



0.25-in Ti 5-1-1-1



0.125-in Ti 6-4

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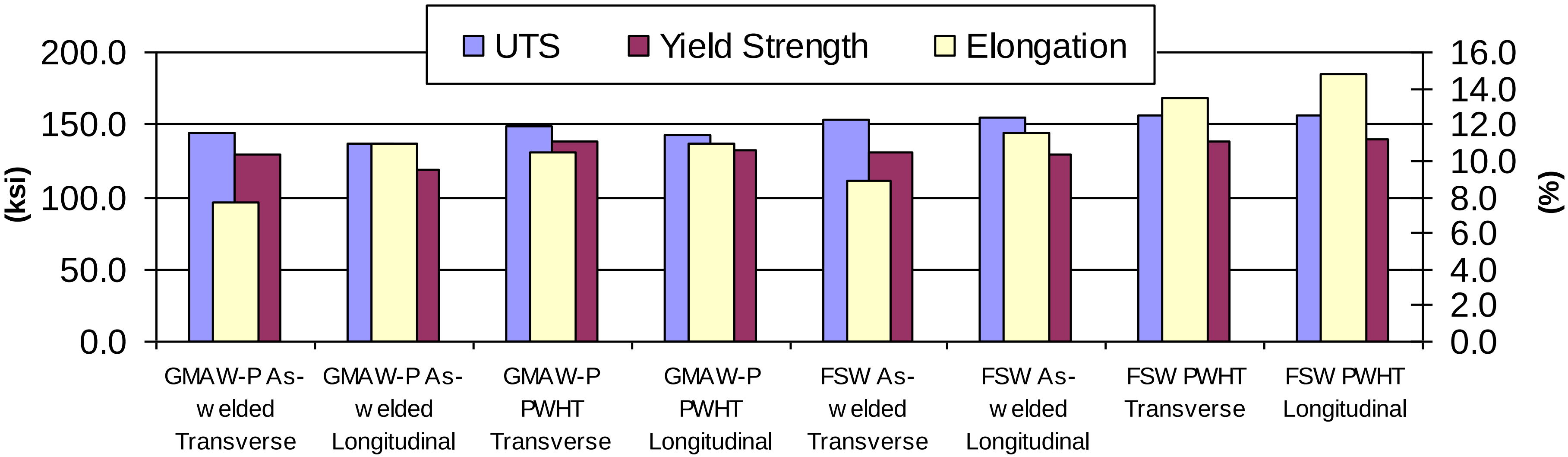
Titanium FSW Static Properties



ASTM E-8 sub-size (1.0-in gauge, 0.25-in dia.), PWHT 1150°F for 2 hrs
GMAW-P failed in the weld metal
FSW failed in the HAZ

- **FSW provides an improvement in static properties over conventional GMAW**
- **When FSW is combined with PWHT, the properties increase dramatically especially elongation**

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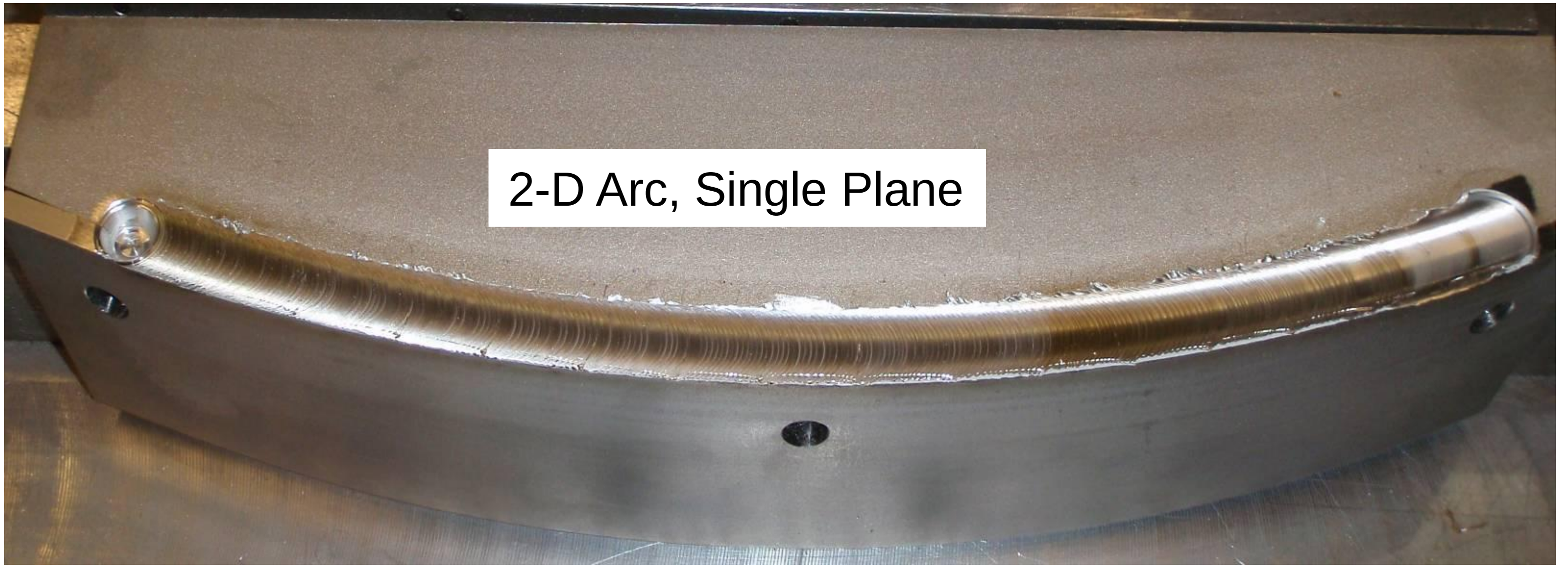
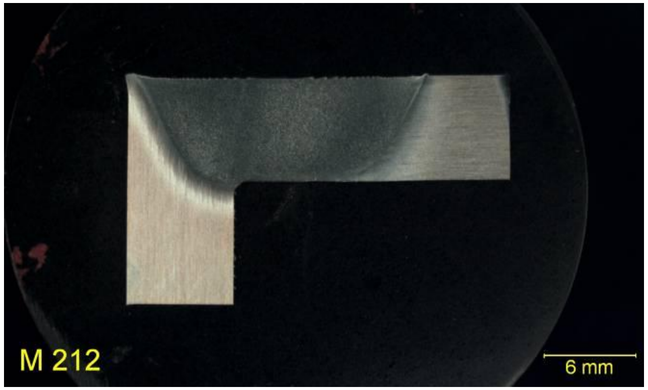
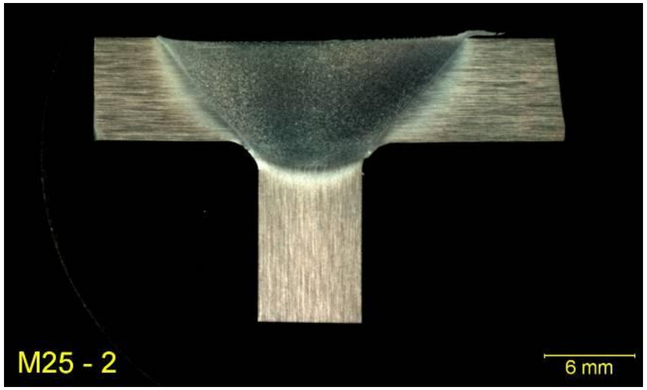
FSW of Ti Capabilities

- **Complex structures possible**







0.25-in thick
Ti 6-4 Joints

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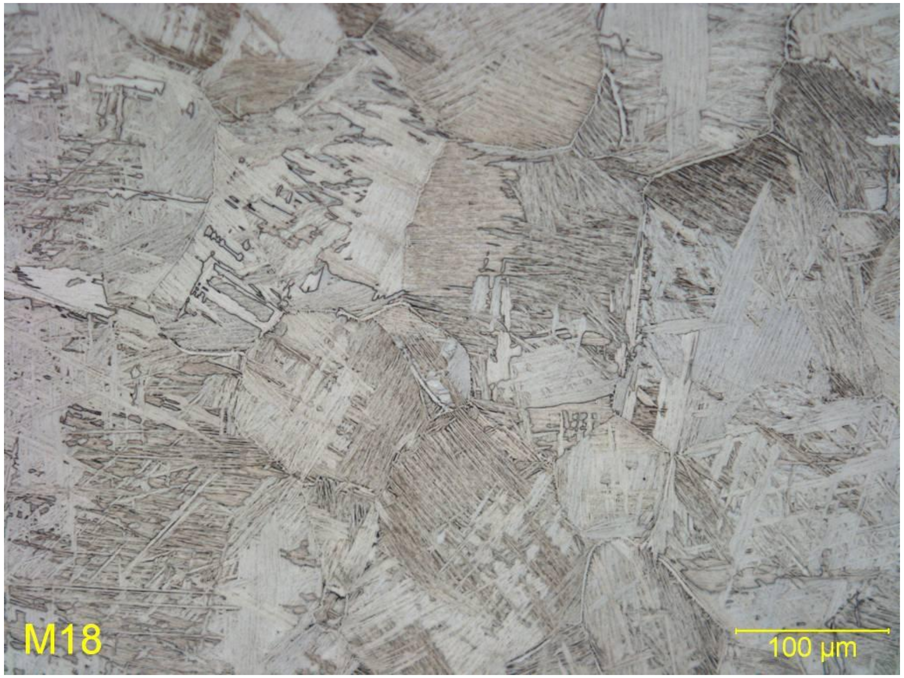
Microstructural Characteristics of Titanium Friction Stir Welds

- **High stir zone temperatures are typically above the β-transus**
- **Upon cooling leads to a range of potential β-decomposition products**
  - α+β Widmenstatten morphology
  - Martensitic (α’ or α”)
  - Retained β
- **Potential for sub β-transus processing**
  - Lower processing temperatures
  - Deformation in α+β phase field
  - Lead to an equiaxed α+β microstructure



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FSW of Titanium Tool Life

- **The challenge for the FSW of Titanium is tool life**
- **Extending this tool life is critical to the success of FSW of Titanium**
  - Expand process window
  - Reduce wear
  - Lower tool cost per part
  - Minimize redresses

Lower Cost

- **On-going research to improve tool life via next generation materials and tool designs**

Tool Material Challenges

- **Typical processing temperature for the FSW of Aluminum around 500°C**
  - H13, 350M, MP159, 4340
- **Typical processing temperature for the FSW of Titanium around 1000°C**
  - Refractory metals such as Tungsten and Molybdenum
- **Typical process forces for the FSW of Ti range from 5,000-lbf to 15,000-lbf along the axis of tool rotation**
  - Can lead to tool deformation
- **Abusive welding environment promotes wear of the material**
- **Tool design critical to generate heat and promote material movement to consolidate weld joint**

Tool Development

- **Material requirements**
  - Strength at temperature
  - Ductile at room and elevated temperatures
  - Chemically inert with work piece
  - Excellent abrasion resistance

$W\text{-}La_2O_3$

- **Tool Design Requirements**
  - Promote material movement
  - Generate required heat
  - Provide adequate consolidation forces
  - Protect tool integrity

Variable Penetration Tool (VPT)

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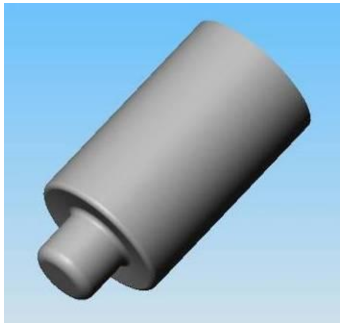
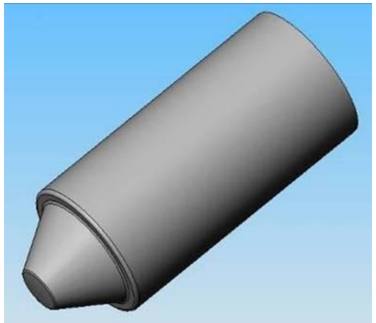
Tool Development

- **Additions of La_2O_3 to Tungsten**
  - Improves creep resistance
  - Increases recrystallization temperature
  - Increases high-temperature strength
  - Provides barrier to material sticking
- **VPT tool design**
  - Provides sufficient vertical consolidation force
  - Wide body pin resists deformation
  - Low thermal conductivity of Titanium drives a minimal shoulder

Conventional Design



VPT Design



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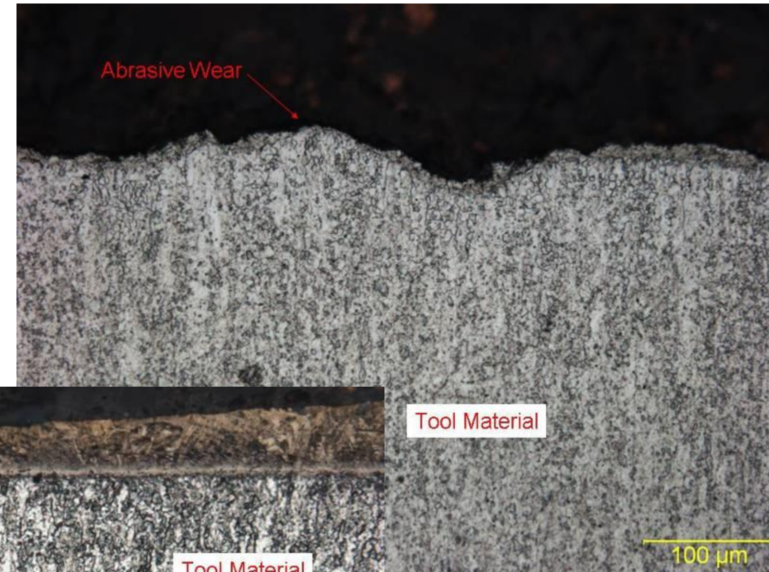
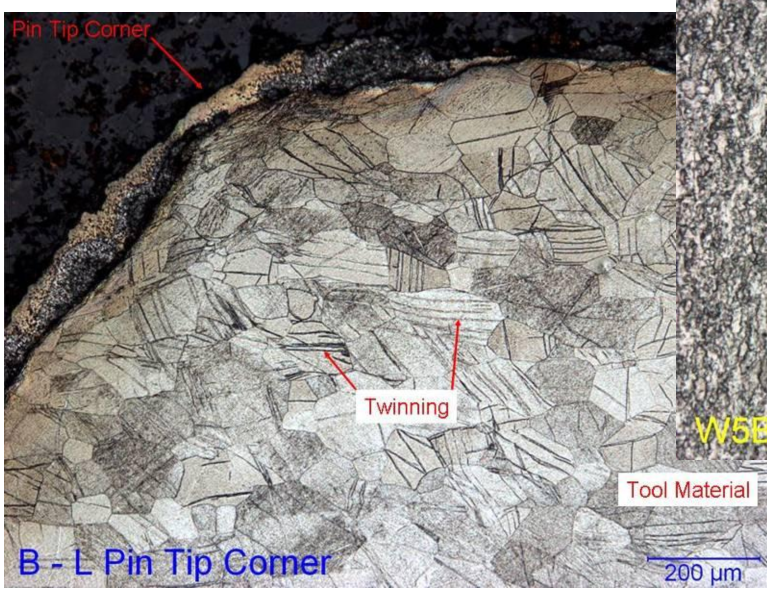
FSW of Titanium Tool Life

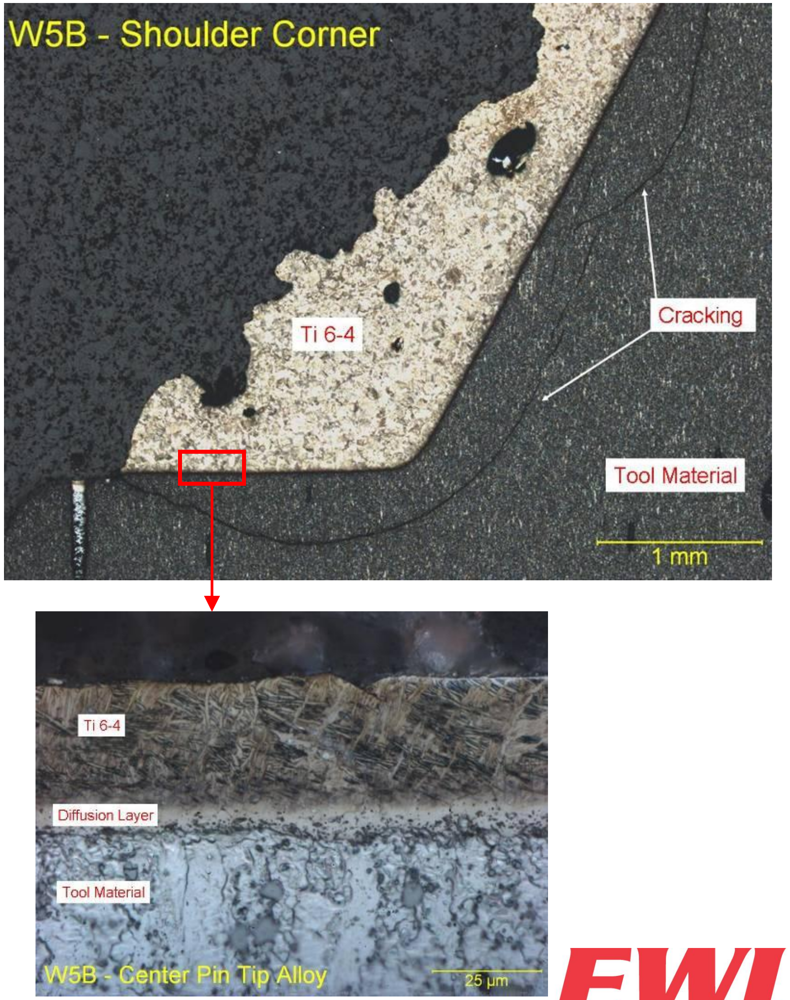
- **Tool degradation in W-based tools occurs by two primary methods**
  - Deformation
  - Wear





FSW of Titanium Tool Life

- **Adhesive wear can lead to diffusion**
  - Promotes cracking in tool
- **Lanthanum Oxide added to Tungsten raises the surface energy**
  - Prevents initial sticking
  - Reduces diffusion potential
- **Next generation tool materials**
  - Investigating ideal La_2O_3 content
  - Other alloying additions to improve hardness
    - Improve wear resistance



Conclusions

- **The Friction Stir Welding of Titanium is a viable manufacturing process**
  - Can be applied to complex joints over a range of thicknesses
- **Advancements in W-based tool material technology has allowed**
  - Deep single pass thickness capability
  - Long expected tool life
  - Degradation resistant tools
- **On-going efforts into next generation tool materials and tool designs**
  - Improve tool life
  - Increase travel speed
  - Reduce tool cost

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