Joining Technologies for Coal Power Applications

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K. S. Weil, G. J. Grant, J. T. Darsell, and Y. Hovanski

Pacific Northwest National Laboratory, Richland, WA

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- **Technology Development Objective:**

  Develop method(s) of joining next generation materials that result in joints with ideally the same hot strength, creep strength, or corrosion/oxidation properties as the base metal

- **Benefits/Goal Alignment:**

  Project supports current and new efforts in developing next generation materials for higher temperature plants → scalable methods of materials joining

Ability to produce joined pipe/plant componentry → **Higher-temperature creep/corrosion resistant materials** → **Higher plant operating temperatures/ pressures** →
- **Reduced CO_2 emissions**
- **Lower variable operating cost (fuel cost)**

- **FY09 Milestones:**
  - **Finalize work on air brazing, including publishing data on filler metal modifications - completed 11/08**
  - **Report on initial FSW parameter studies conducted on ODS plate - completed 5/09**
  - **Conduct tensile testing on FSW joined ODS plate materials - completed 8/09**
  - **Conduct microstructural analysis of FSW joined ODS plate materials - completed 9/09**

Issues/Problem Statement

- **Boiler component material families:**
  - Ferritic steels
  - Austenitic steels
  - Ni-based superalloys

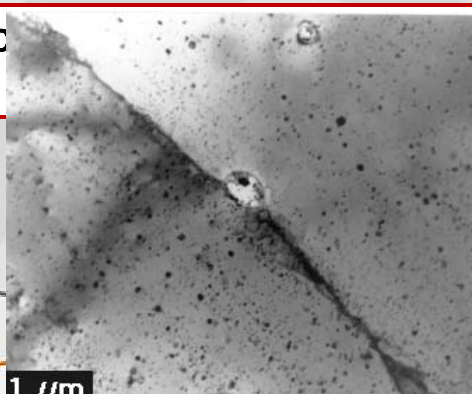
↑ Lower material cost

↓ Increased hot strength and resistance to creep/corrosion

- Higher thermal conductivity
- Lower CTE
- Less susceptibility to fatigue cracking

- **Heavy section components:**
  - Minimize thermal fatigue
  - Maximize creep strength

- **Oxide dispersion strengthened (ODS) alloys:**
  - Addition of insoluble, nanoscale dispersoids to ferritic alloys greatly improves their high-temperature mechanical properties
  - Critic ction viable method joining of components (e.g., e materials



MA 956

H. K. D. H. Bhadeshia, Univ. of Cambridge website

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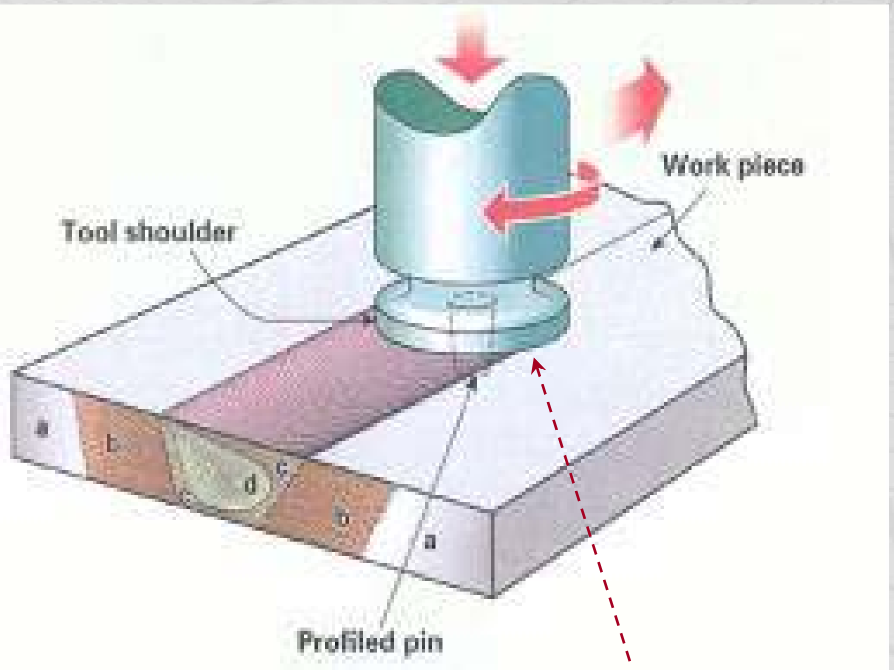
Solid-state joining process (no material melting)

- Spinning, non-consumable tool is plunged into the surface of a material
- Heat from friction and plastic work lowers material's flow stress
- Tool moves through the softened material along the joint line causing material flow from front of the tool to the back into the joint gap
- The resulting joint is characterized by:
  - Fine-grained "nugget" composed of recrystallized grains (d)
  - Surrounded by a mechanically deformed region (c) and a heat affected zone (b)

FSW was invented by TWI, ltd in 1991



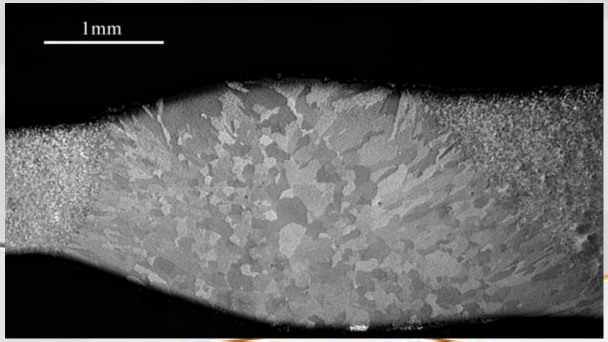
FSW Process Advantages

Technical

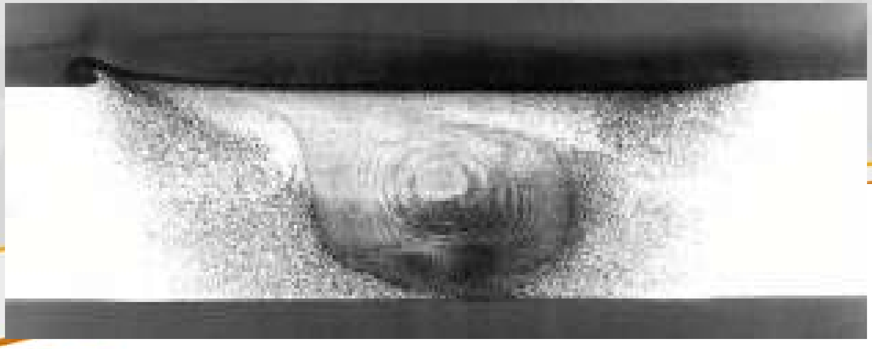
- Higher strength joint
- Improved fatigue performance
- Higher toughness, better damage tolerance
- Fewer defects
- Fine grain nugget is more amenable to NDE (x-ray, ultrasonics, etc.)
- Fine grained nugget less susceptible to hydrogen induced cracking
- Lower distortion
- Lower heat input:
  - Reduced residual stress
  - Smaller HAZ
  - Reduced sensitization for corrosion

Economic

- Single pass method – faster on thick section welds
- Fewer consumables
- No environmental emission
- No “expert” operators
- Lower recurring costs (but higher initial capital costs than GTAW/GMAW)
- Lower energy costs



Fusion Weld (Al)



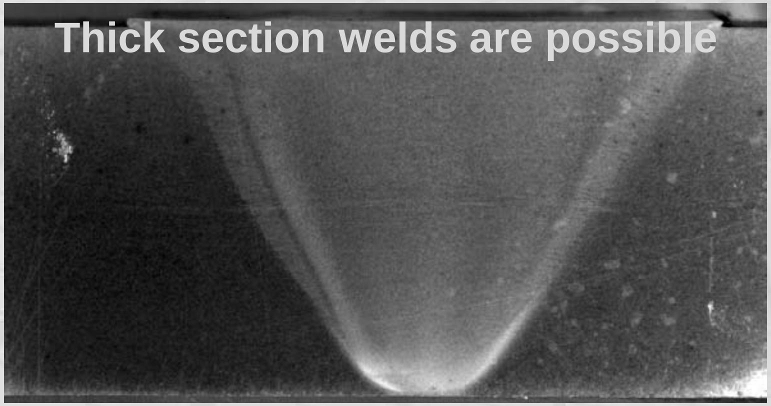
Friction Stir Weld (Al)

Commercial Viability

8 ft x 56 inch working envelope

FSW equipment at Pacific Northwest National Laboratory

Thick section welds are possible



0.5” thick, single pass Friction Stir Weld in HSLA 65

Circumferential FSW – pipe welding

Approach in FY09 - 10

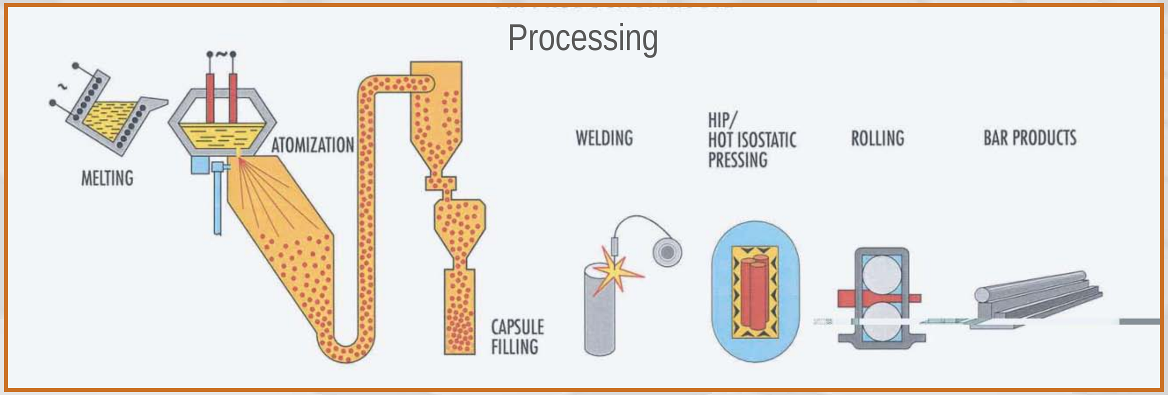
- **Joining studies:**
  - **Plate joining – examine process parameters (i.e. spindle rotational and travel speeds, plunge force, and pin diameter/shoulder geometry) that maintain uniform oxide dispersion and promote grain size matching across the joint**
- **Mechanical testing:**
  - **Room and elevated temperature tensile property measurements**
  - **Performance-based defect (strain localization) testing**
  - **Creep testing**
- **Issues around commercialization** **(Leveraged work from other programs)**
  - **Feedback process control**
    - **System control algorithm that ensures weld quality is within acceptable design tolerances and can meet certification requirements**
  - **Thick section welding (up to 5/8” single pass)**
  - **Circumferential welding on pipe or pressure vessel geometries**

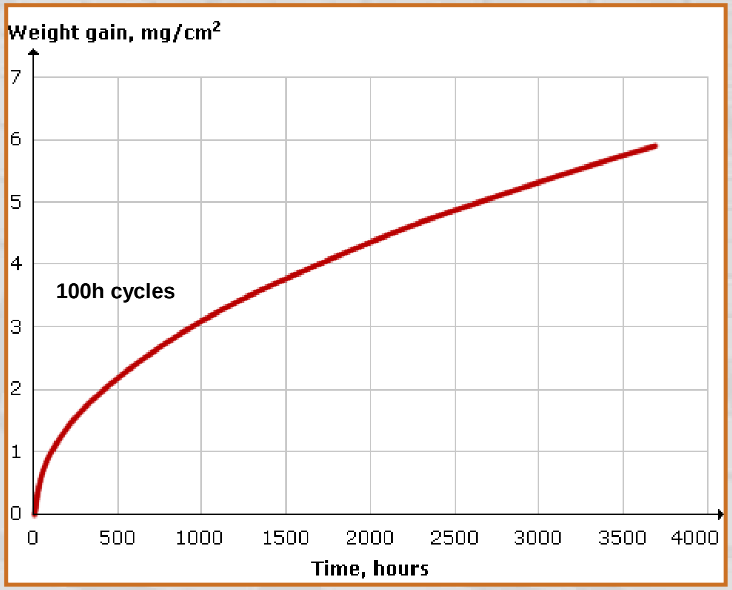
Initial FSW Trials on Kanthal APMT

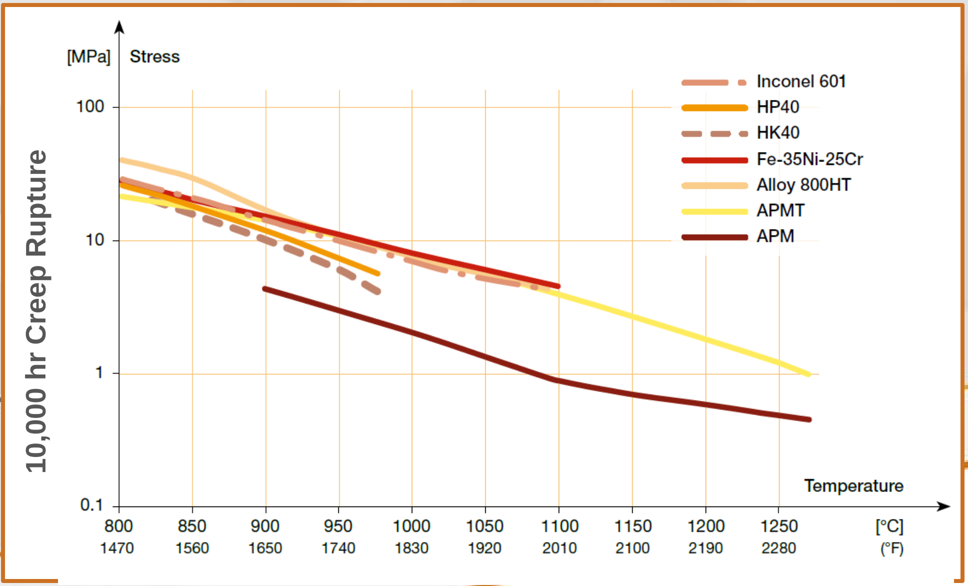
Kanthal APMT - Ferritic dispersion-strengthened alumina former

Composition (wt%)

Fe	Cr	Al	Y	Zr	Hf	Ti	C	S	N
Bal	20 - 23	5.0	0.1	0.05	0.1	0.02	0.03	0.002	0.05







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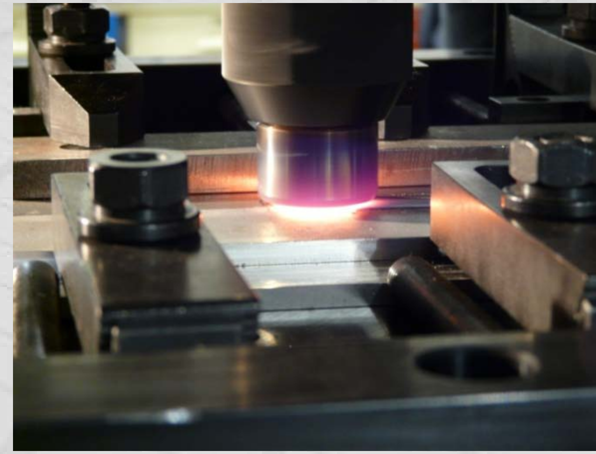
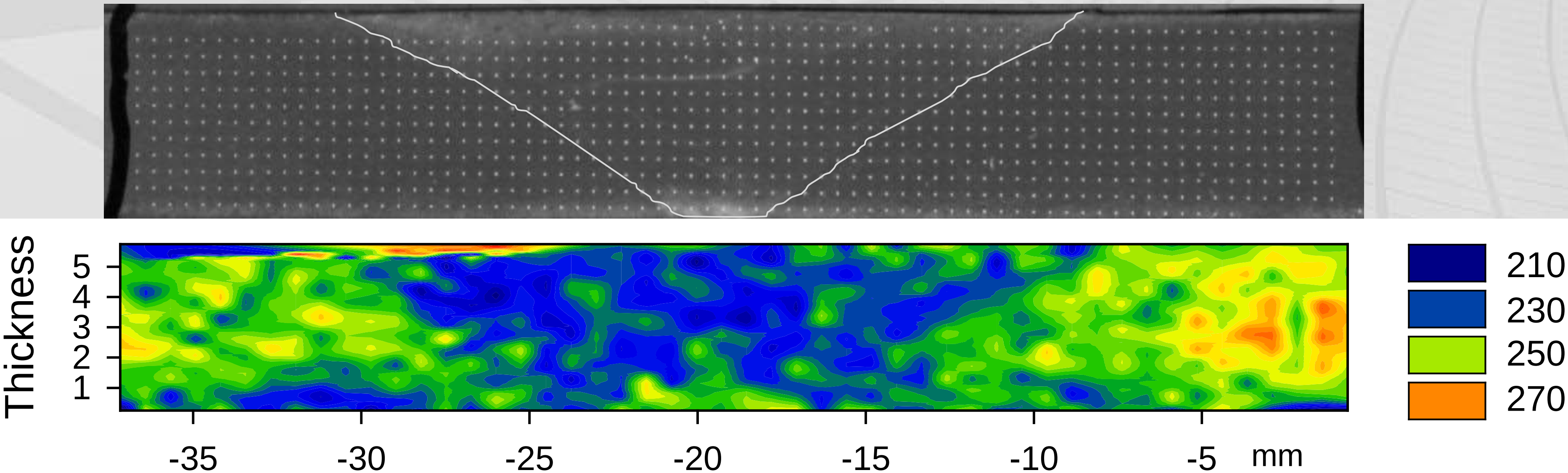
- Tool: PCBN Convex scrolled shoulder stepped spiral pin tool, 0.25” pin length
- Process Variables:
  - Weld speed (4 – 8 ipm),
  - Spindle speed (300 – 600 rpm),
  - Tool load (load controlled at 3000 – 7000 lbs)

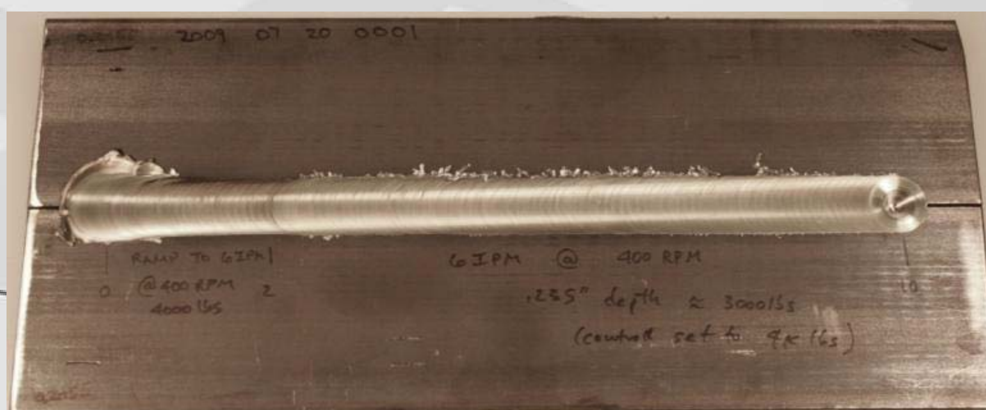


0.25”

Fully consolidated, defect-free welds were made under a range of process parameters

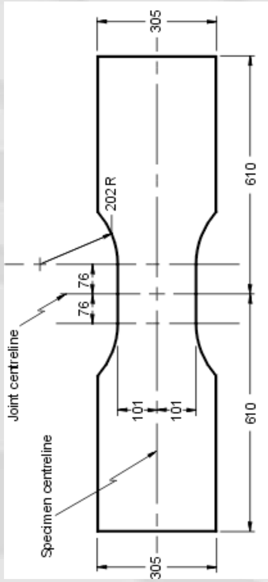
- **Uniform softening (slight) inside the nugget and HAZ**
  - **HAZ on Advancing Side (left) shows slightly more softening**

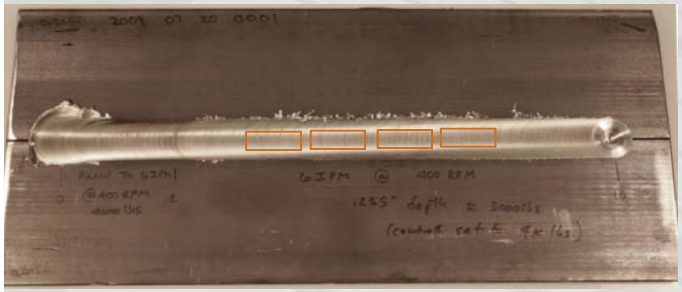


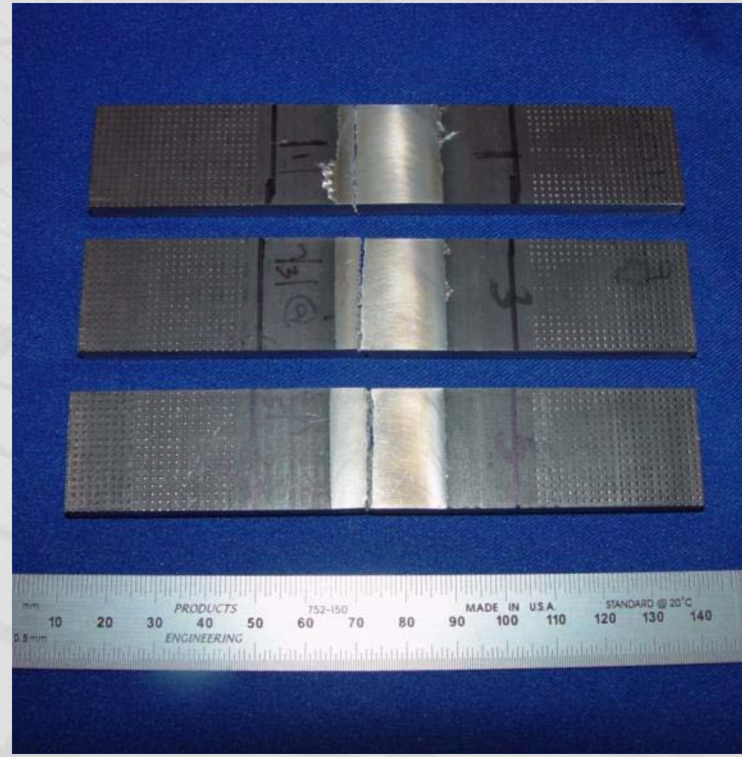


Full penetration, 300 mm long butt weld in 6.2 mm (¼”) thick plate

Room Temperature Mechanical Properties



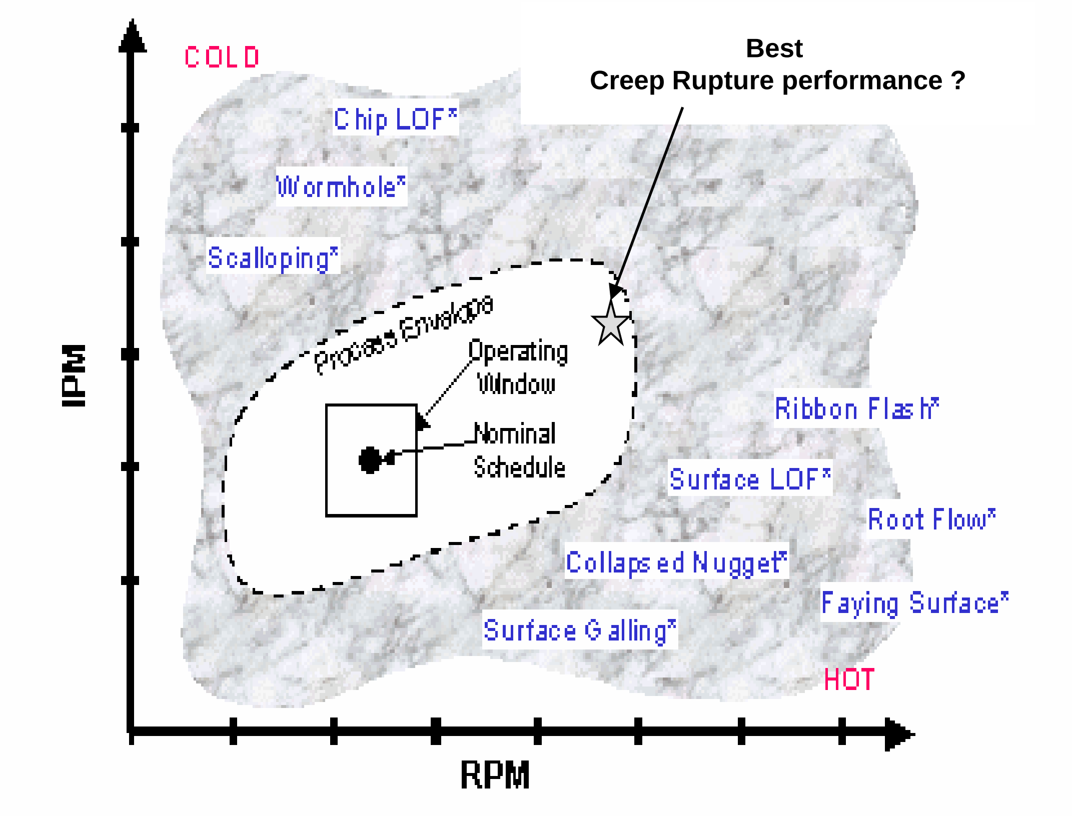




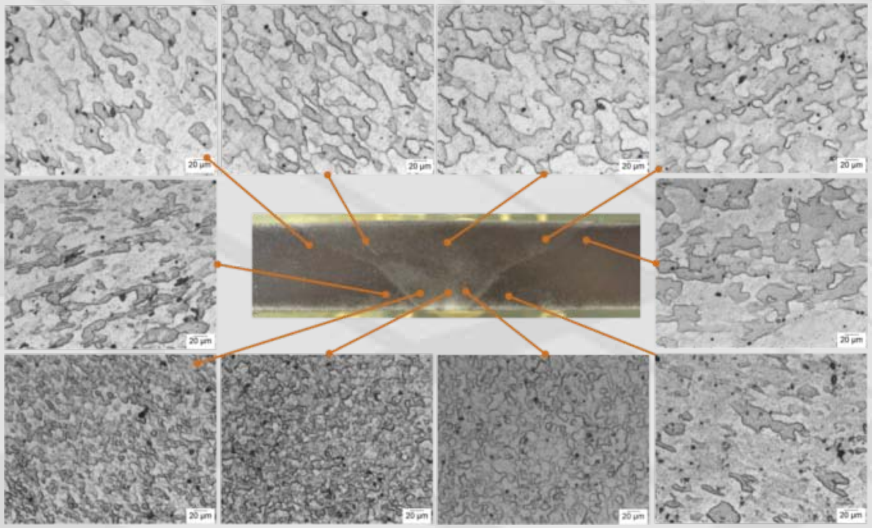
- **Kanthal APMT Properties**
  - **Yield Strength (.2% offset): 543 MPa**
  - **Tensile Strength: 742 MPa**
- **Weld Metal Properties:**
  - **Yield Strength: (.2% offset) 540 MPa**
  - **Tensile Strength: 690 MPa**

Detailed Approach

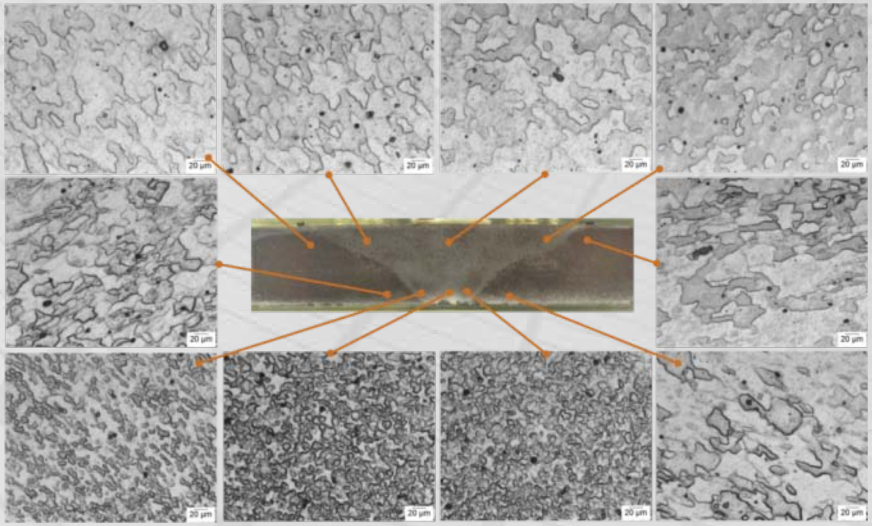
- ***Weld trials to discover process window***
  - This task will involve a detailed and systematic investigation into the weld parameters and weld conditions required to produce consolidated, volumetric defect free weld joints.
  - Variables considered will include: RPM, IPM, Forge Force, and Tool design/material
  - The process window is usually large enough that the microstructure can be tailored to produce welds with different mechanical properties



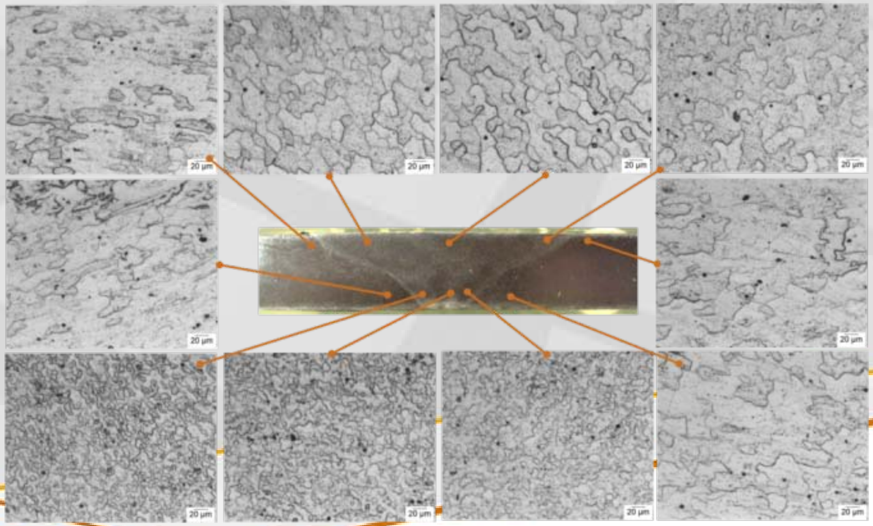
Microstructure at Various Process Parameters



400 rpm – 6 ipm #1

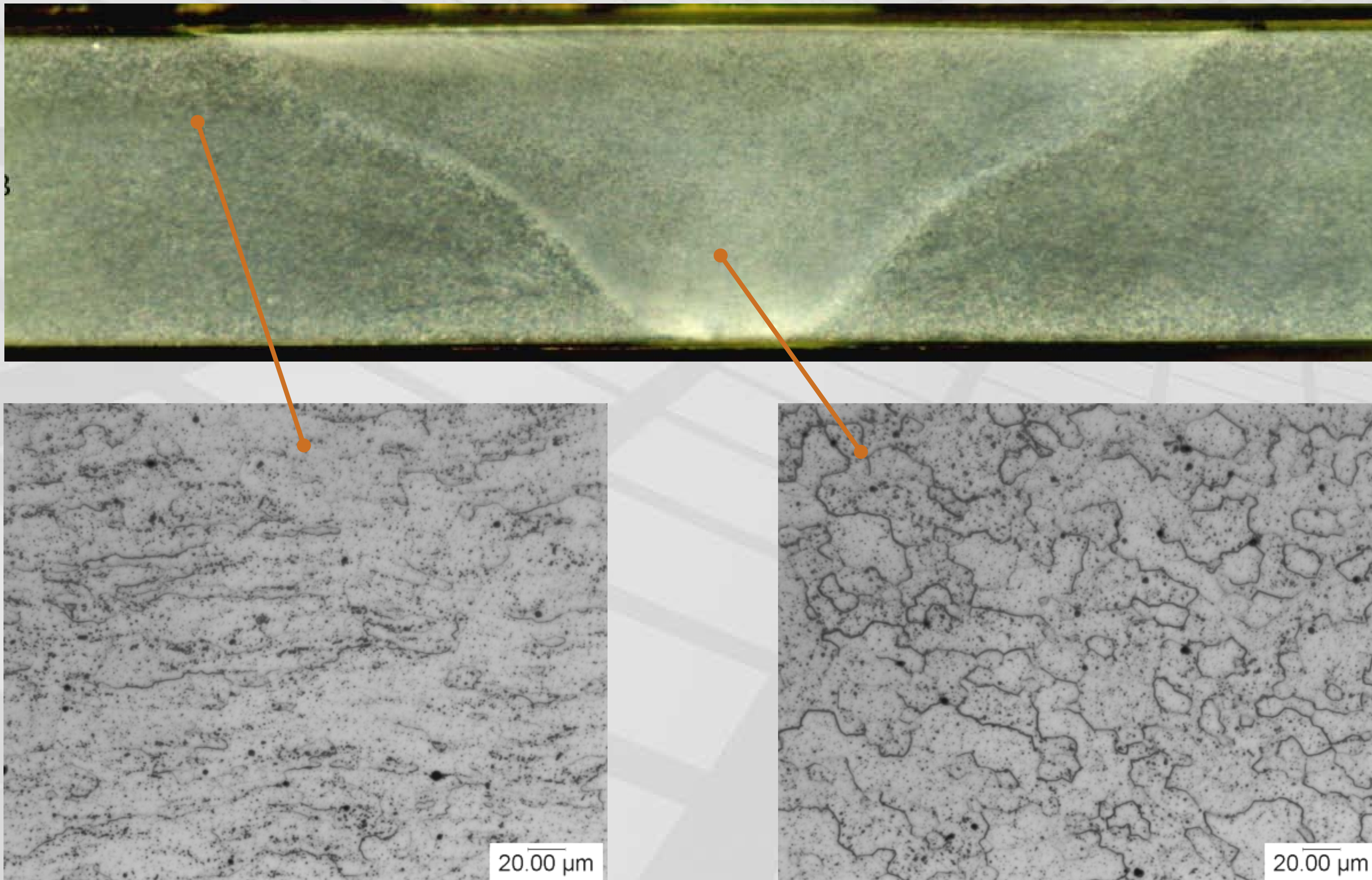


400 rpm– 6 ipm #4



400 rpm – 7 ipm #4

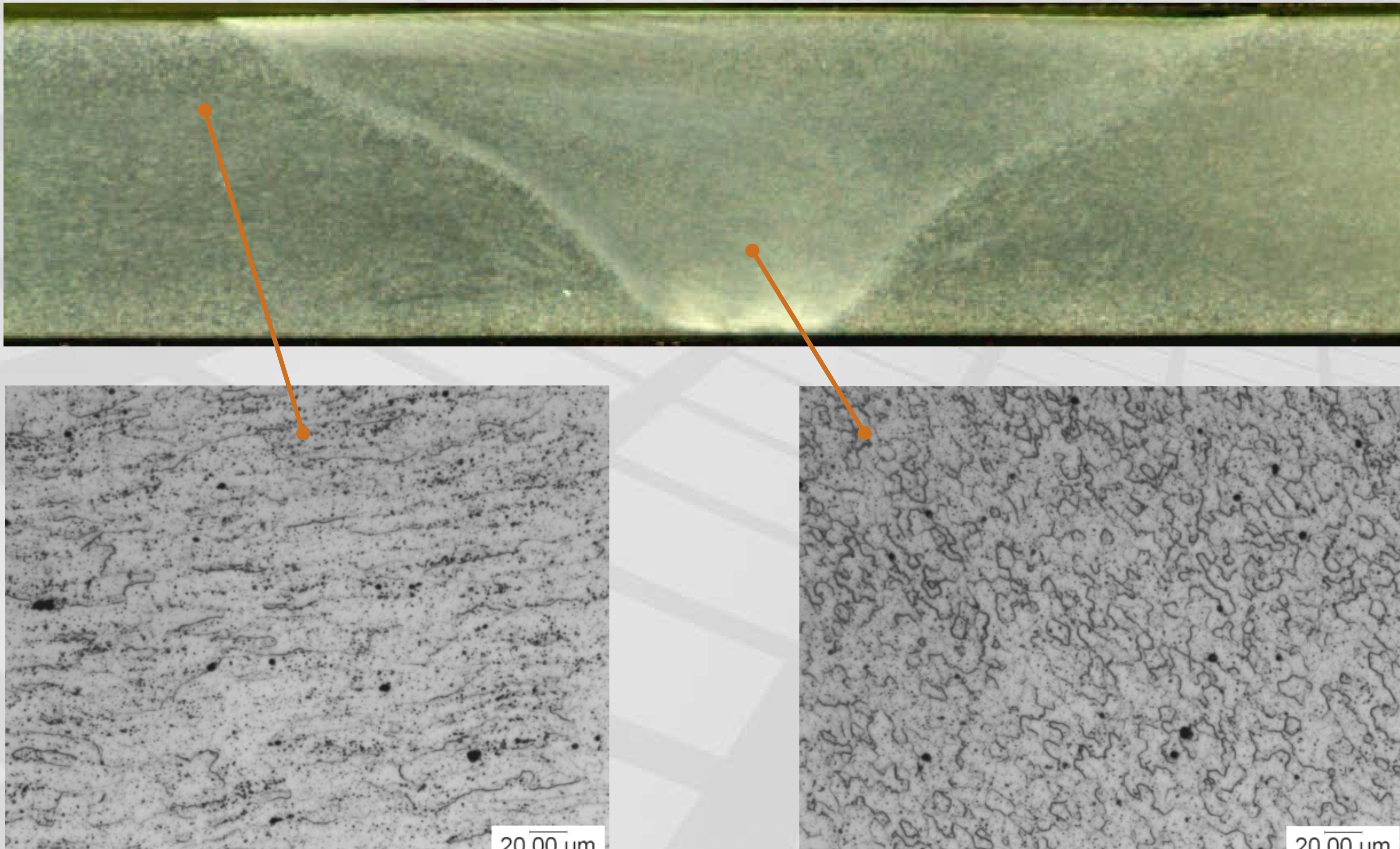
Microstructure in FSW Kanthal Weld (6 ipm)



Ferrite grain size of nugget about the same as parent sheet, but more equiaxed

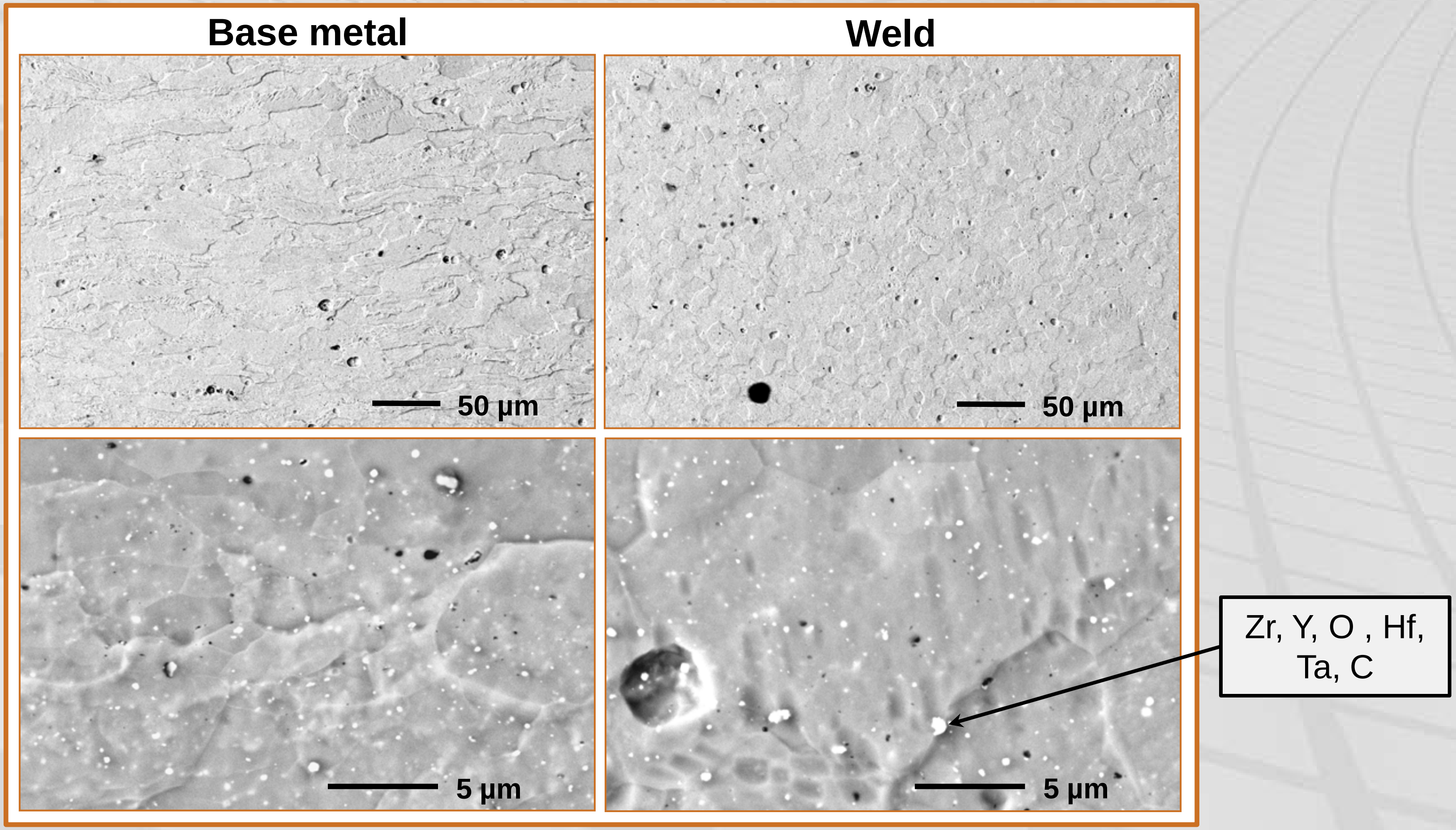
Microstructure in FSW Kanthal Weld (7 ipm)

Slightly higher linear speed and x-direction load



- **Change of process conditions will change nugget microstructure- in this case, finer grain ferrite at higher travel speed**
- **Creep properties (based on grain size) can be customized to the parent sheet**

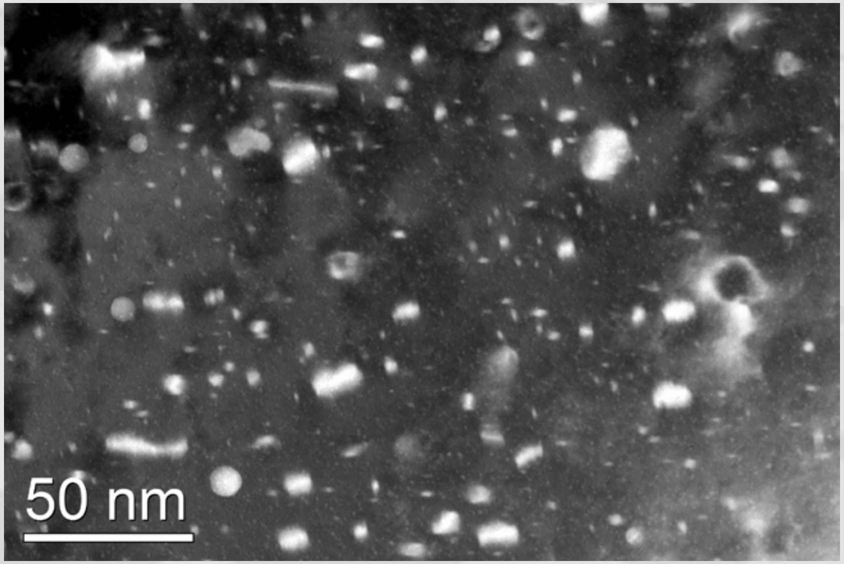
Microstructure in FSW Kanthal Weld

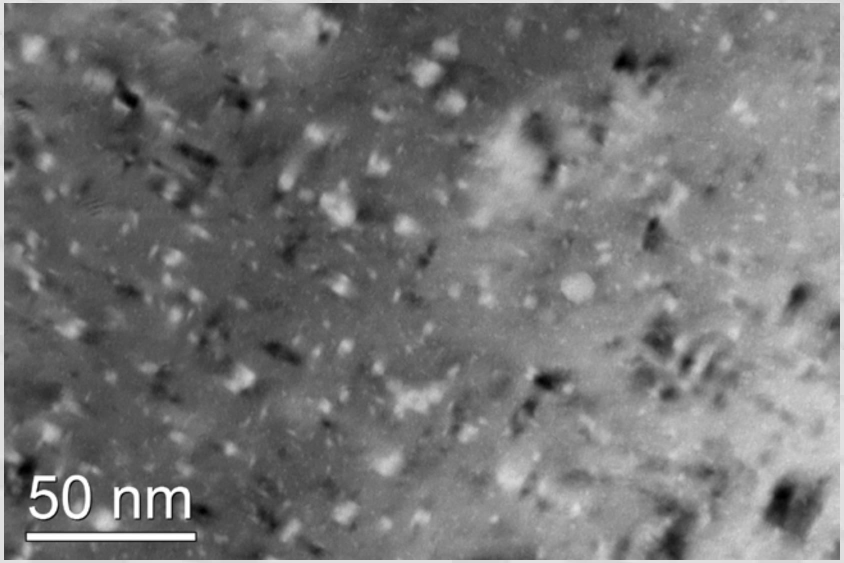


- **Carbide and Oxide particles generally are ≤ 600nm**
- **Distribution of these relatively large particles is as uniform in the nugget as it is in the parent sheet**
- **Unlike fusion welding, there is no segregation of these particles**

Are Nanophase Particles Preserved? - GlidCop analog

- Some debate in literature
  - Work done at PNNL 6 years ago showed coarsening in MA957
  - Work done by Odette and others showed no coarsening in welds done at very different process parameters (much colder welds)





- GlidCop analog (traditionally processed ODS Cu alloy)
- 10 nm Al_2O_3 are found in roughly same concentration in weld metal as in nugget from limited TEM work.
- SANS would be more conclusive, but in this work no coarsening or partitioning of the dispersoid was observed

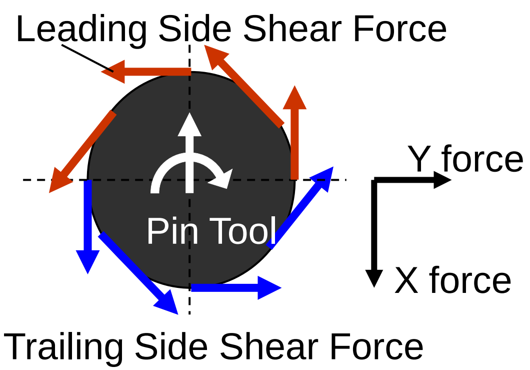
Conclusions

- **Objective: to develop joining technologies for advanced and next generation alloys/materials**
- **Progress to date (in Kanthal APMT):**
  - **Carried out parametric FSW studies**
  - **Hardness results indicate minor differences from base metal to the nugget**
  - **Room temperature mechanical properties – little difference between the weldment properties and those of the base metal**
  - **FSW leads to an equiaxed microstructure in the nugget**
  - **Little change in the distribution of the carbide particulate**
  - **Cu analog: little change in the distribution or size of the oxide dispersoids**
- **Near-term efforts:**
  - **Measure high-temperature mechanical properties and creep in the weldment and base metal materials**
  - **Conduct prototypic oxidation testing on the weldment and base metal materials**

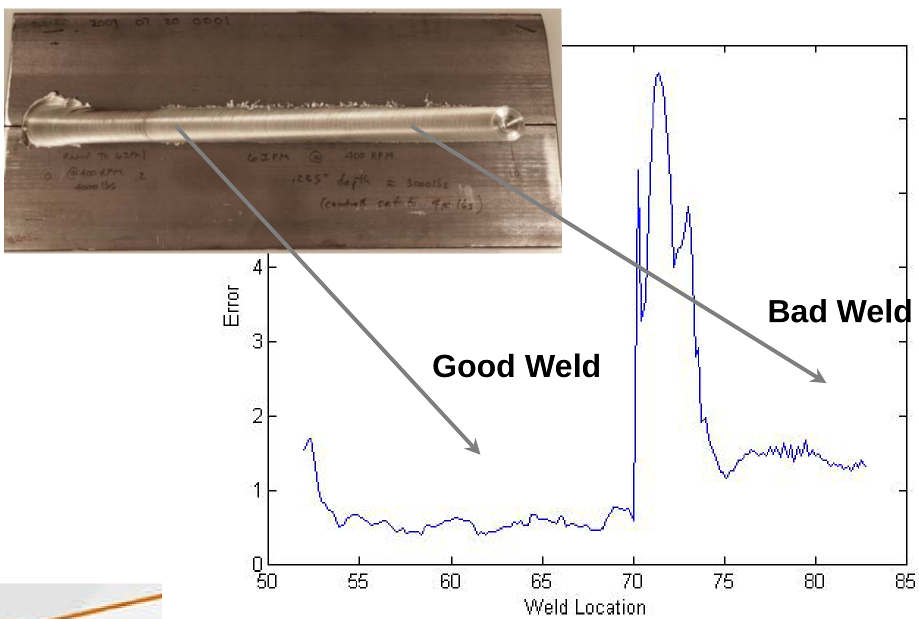
Future Plans

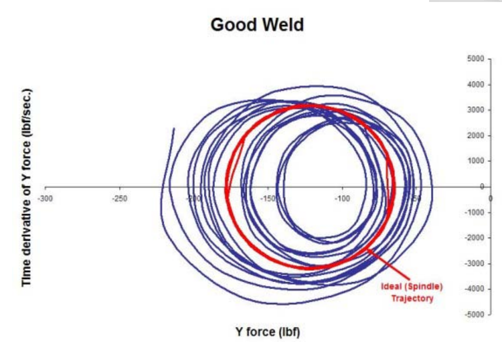
- **FY10 Milestones:**
  - Publication of final work on air brazing development work – completed 12/09
  - Report on results from mechanical testing and microstructural analysis of FSW dispersion strengthen materials – completed 2/10
  - Initiate parametric study on FSW of a representative superalloy material – welds completed on representative Nickel alloys (718 and C-22)
  - Conduct microstructural analysis of FSW joined superalloy materials – due in 9/10
- **Next year's focus:**
  - Conduct performance-based defect (strain localization) testing – working toward an eventual ASTM code case for joints in ODS and Ni based superalloys
  - Examine oxidation properties of FSW joint region in comparison with that for the base metal
  - Demonstrate process deployability
    - Circumferential welds on cylindrical geometry
    - In-situ weld control and quality measurement

- **The nature of the FSW process (machine process under feedback control) means that each weld has detailed records of weld forces.**

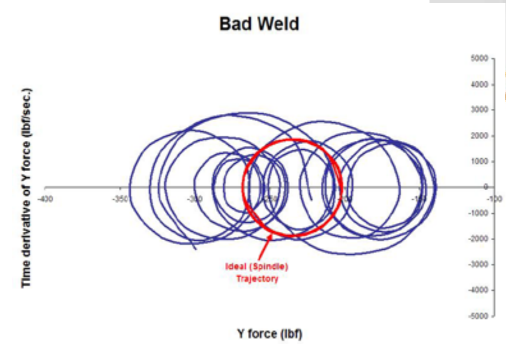


- **Y feedback force is the result of two competing shear forces – the leading side shear force and the trailing side shear force.**
- **The leading side shear force tends to decrease Y force, while the trailing side shear force tends to increase Y force**
- **These two competing shear forces define the equilibrium point of Y force**

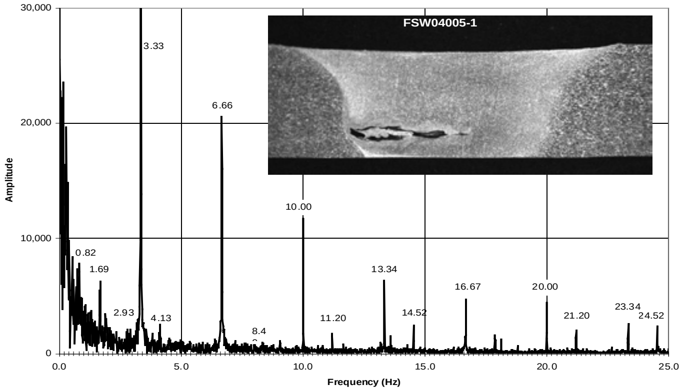


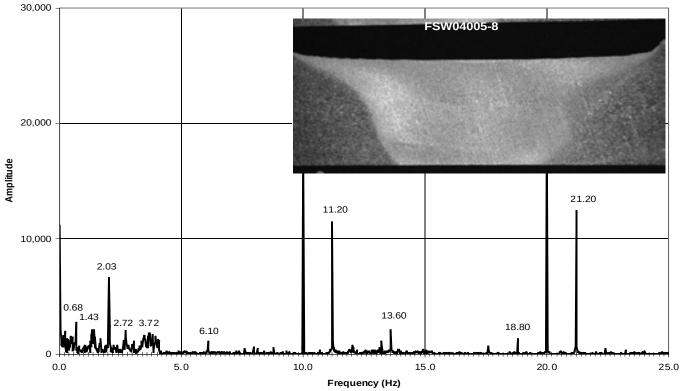


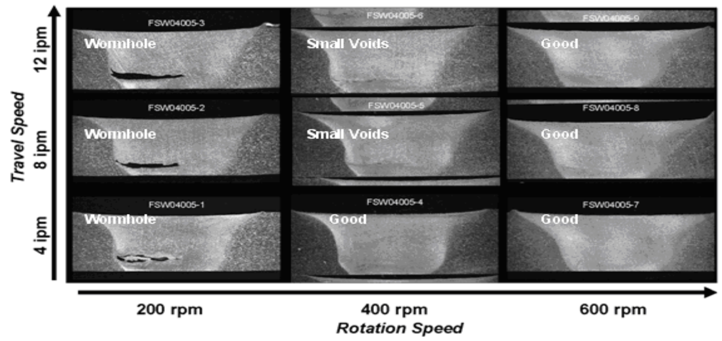
Time derivative of Y force

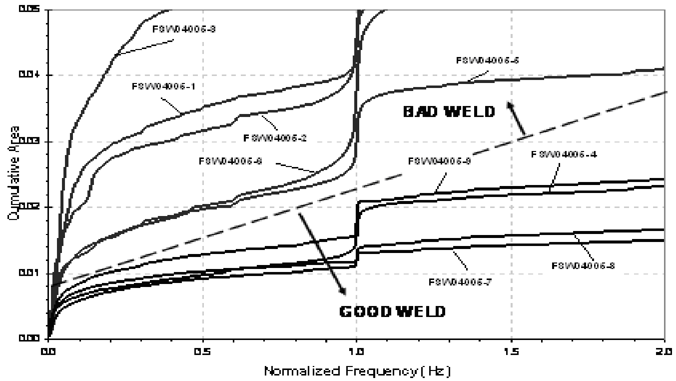


In-Situ Weld Quality Measurement/Control









(W. Arbegast, SDSMT, 2004)

- **The nature of the FSW process (machine process under feedback control) means that each weld has detailed records of weld forces.**
  - **Welds Certs and quality assurance**
  - **Can potentially replace NDE in difficult to inspect environments (inner walls or tube/tube sheet joint)**
  - **SPC real time process control**

Thank You

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Kanthal APMT Mechanical Data