Solid State Joining of High Temperature Alloys for USC and Heat Exchanger Systems

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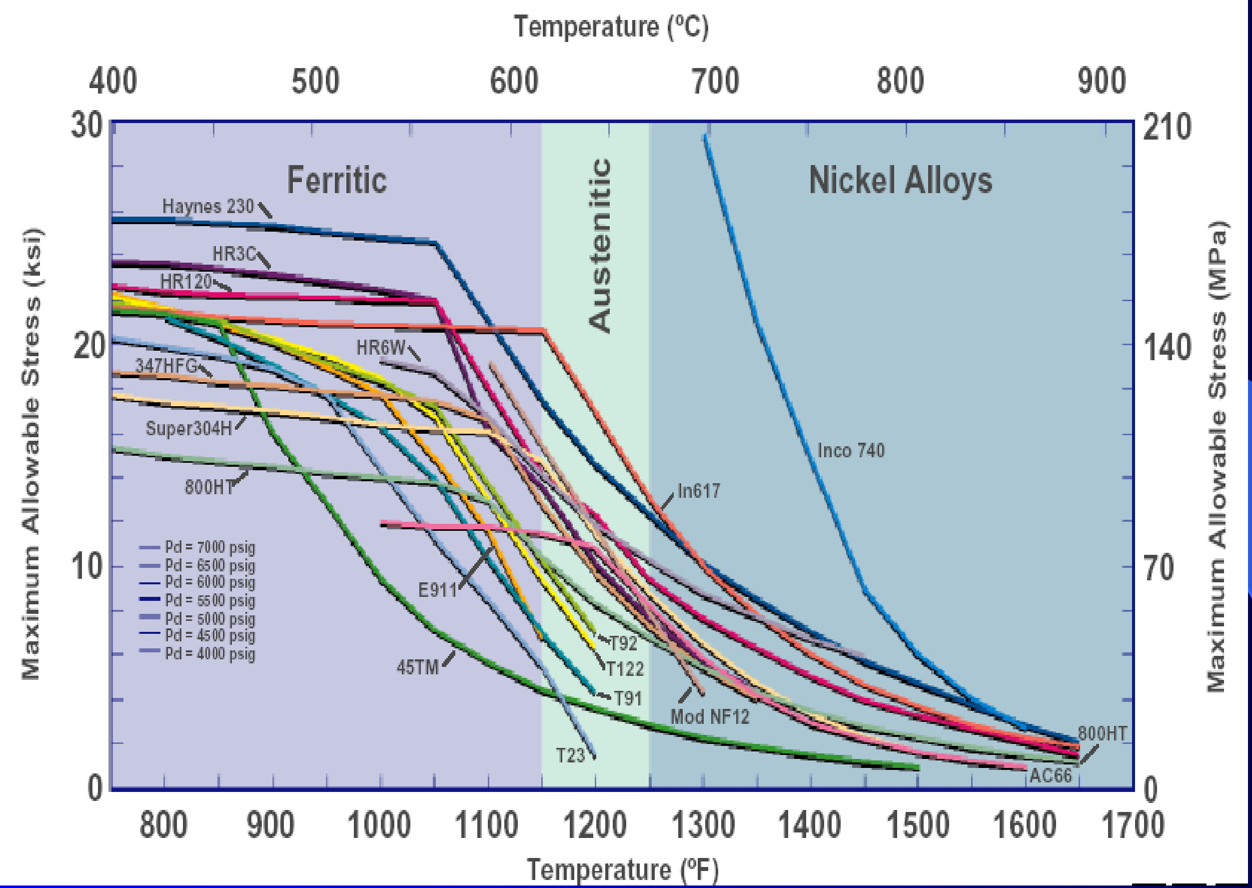
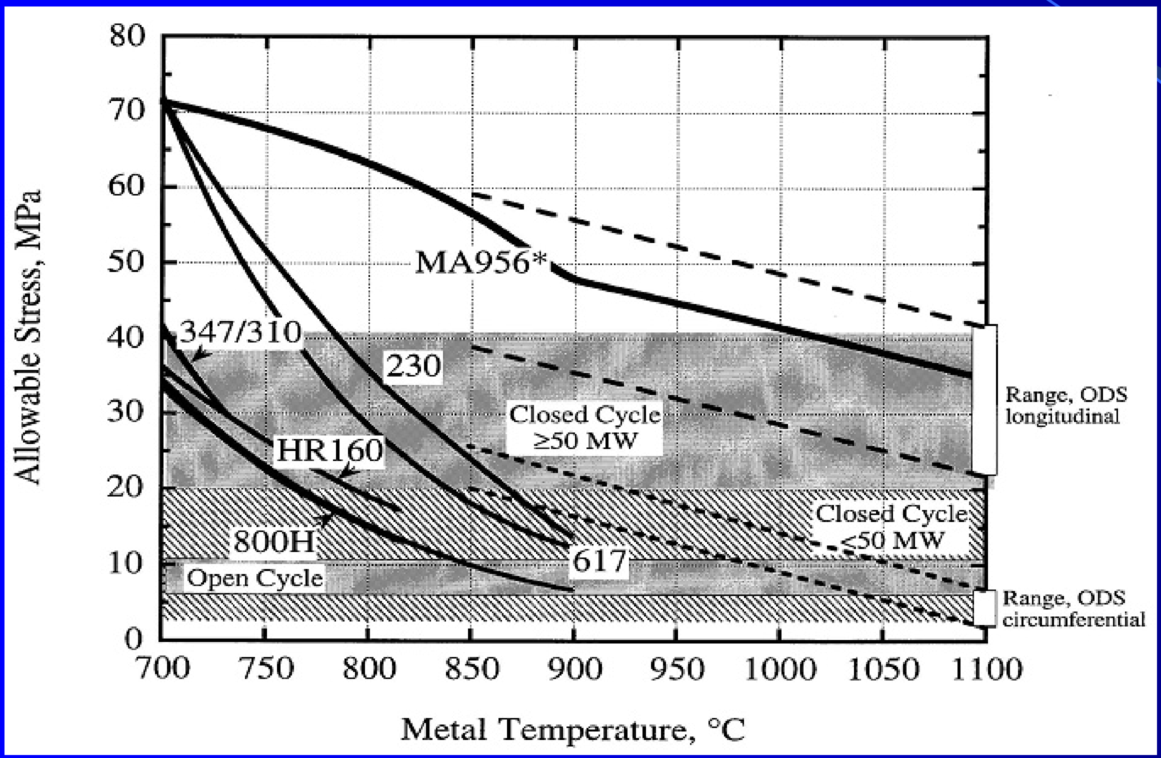
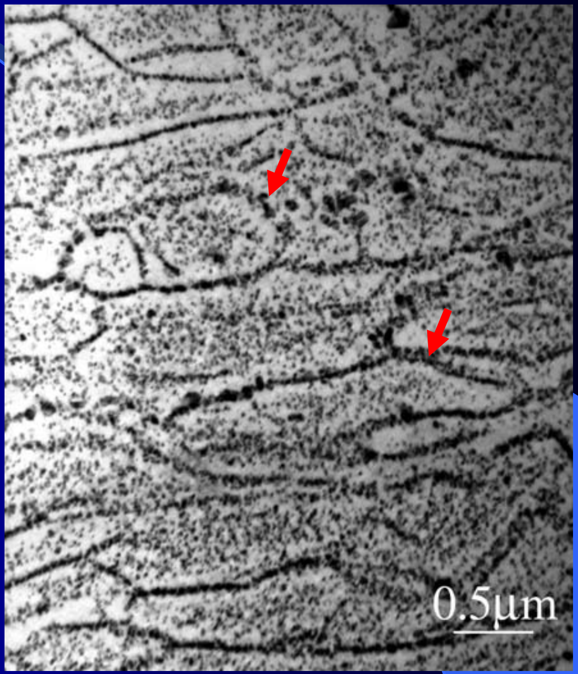
Project Rationale: Material Selection



Material selection grid for the USC Rankine Cycle program indicating the gradual migration from ferritic to austenitic steels to the advanced Ni-base alloys for higher temperature performance. (Source: EPRI, USC Program)

Project Rationale: Material Selection





DOE material metric for HIPPS and IGCC concept heat exchangers for service at 1000^{o}C and above. Note that ODS MA956 Fe-C-rAl alloy is a suitable metallic material for this service.

Project Rationale: Joining Issues

- *Power generation needs for high temperature materials prompts migration from the ferritic, austenitic steels to Ni-base or ODS Fe-Cr-Al alloys*
- *Both the high alloy content Ni-base and Fe-Cr-Al ODS alloys have issues with fusion based joining*
- *IN740 alloys exhibit liquation cracking in HAZ*
- *ODS alloys have dispersoid segregation issues*
- *Component fabrication efforts are predicated on devising viable enabling joining methodologies.*

Presentation Outline

Experimental Configurations & Particulars

Progress Till Date

- Inertial welding: butt joint configurations

- Similar Metal/Alloy Joints

ODS alloys

Solid Solution Ni-Cr, Ni-Cr-Mo alloys

Precipitate Strengthened Ni-Base alloys

- Dissimilar Metal/Alloy Joints

Any combinations of the above 3 classes

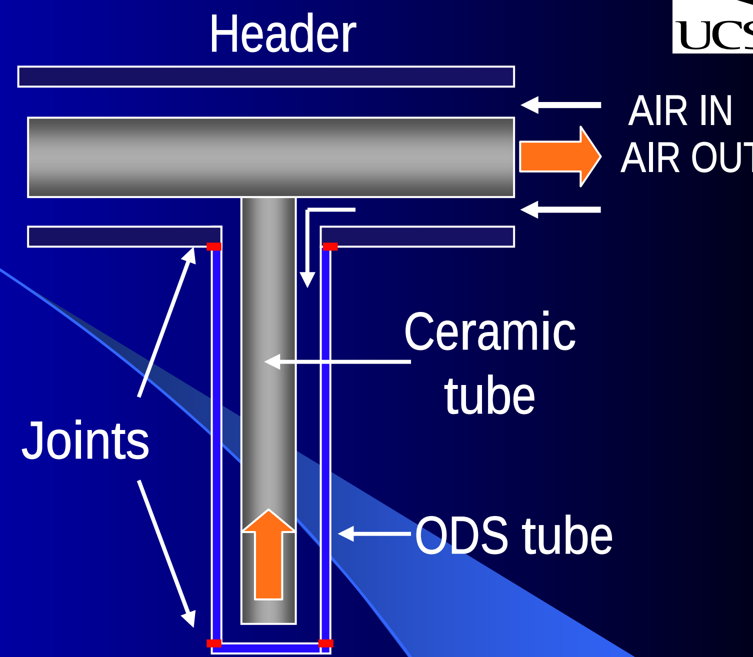
Non-Fusion Joining Efforts

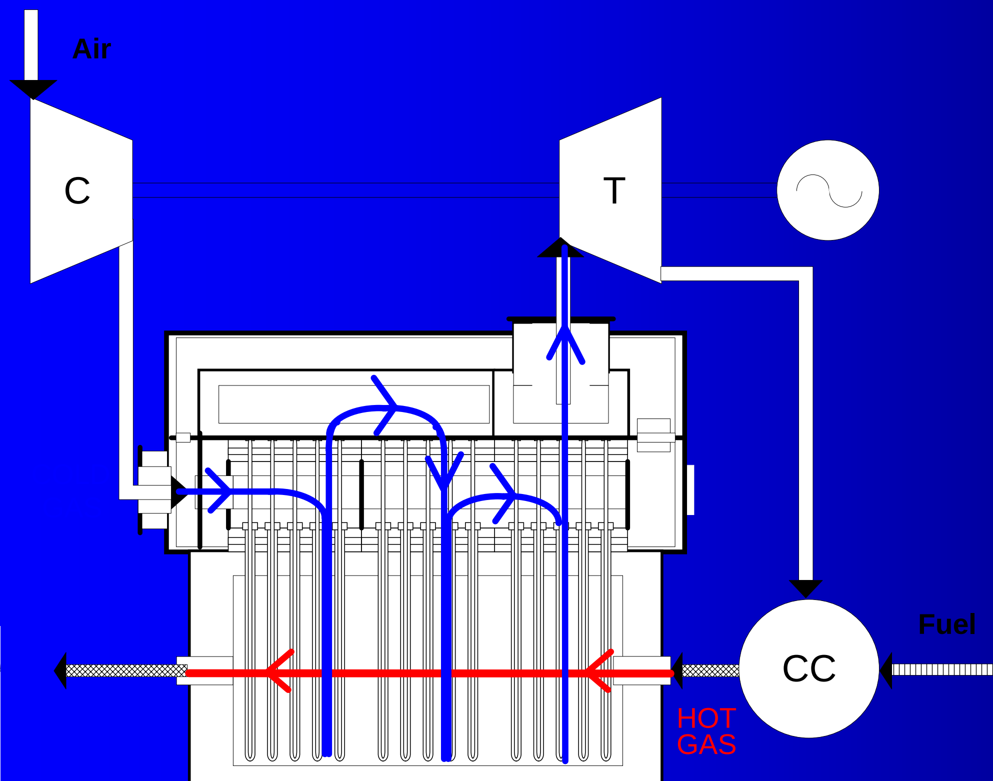
Bayonet Tube Design:

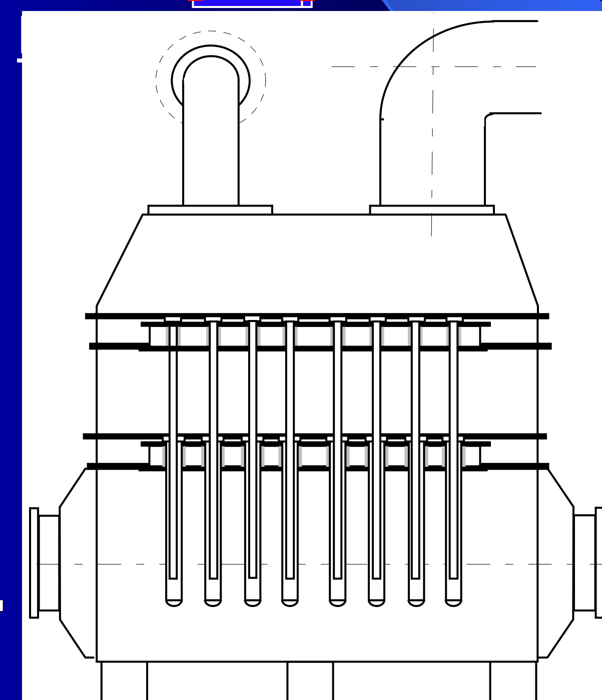
Source: UK Cost 522 Program

HTHE Prototype, Pressurized

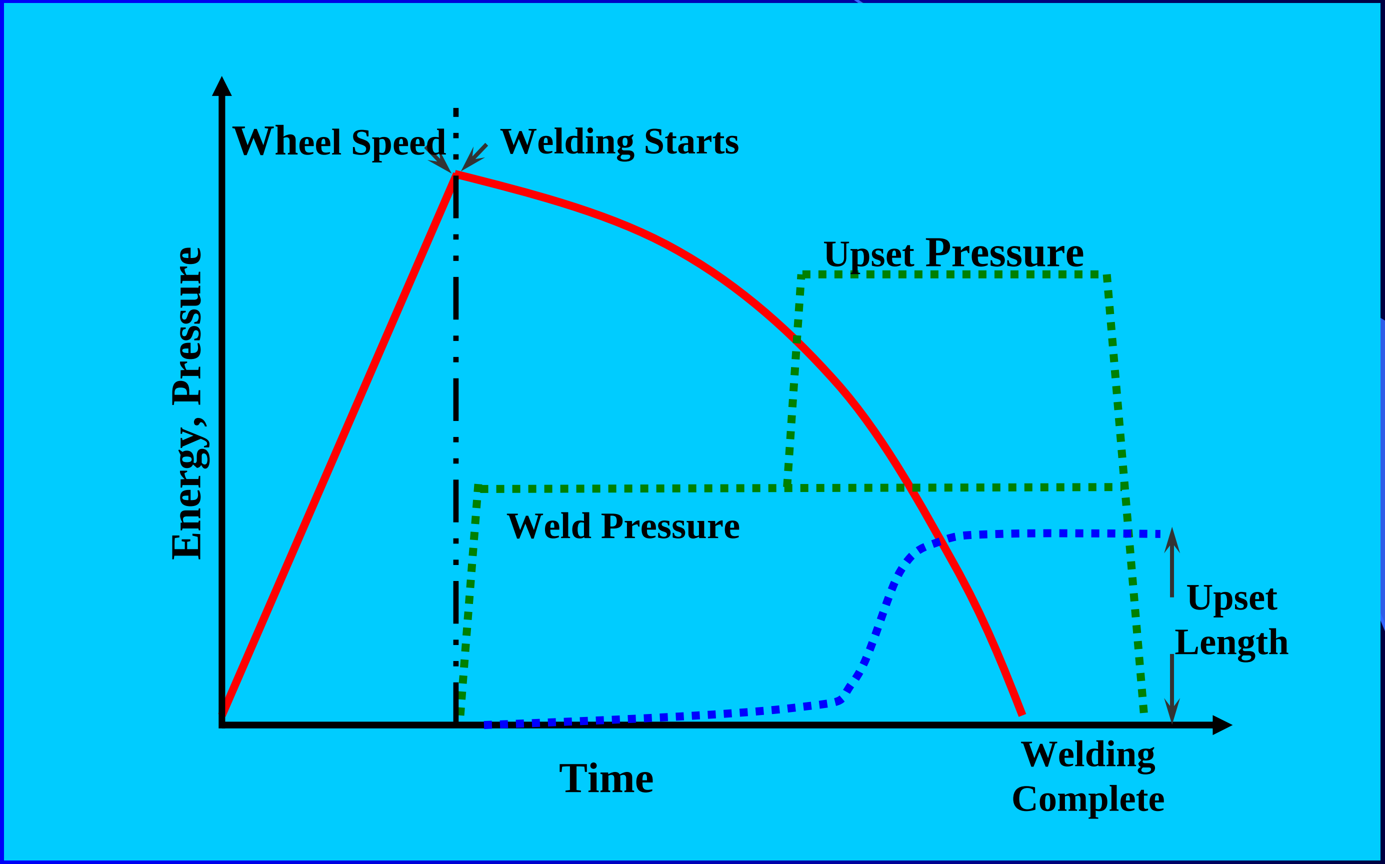
Max 40 tubes, 2”OD, 40” long





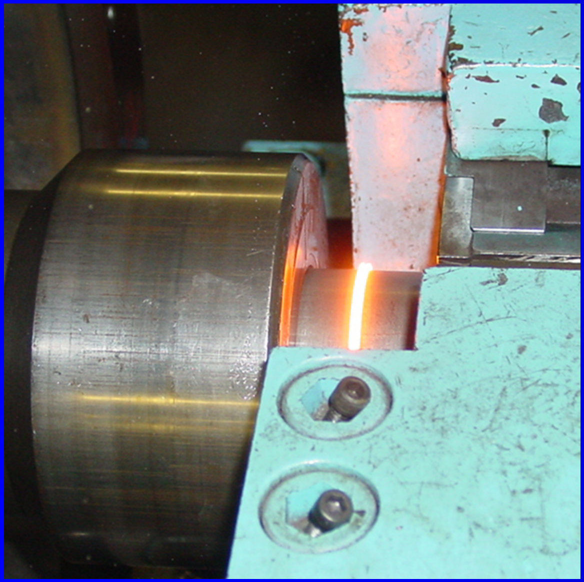


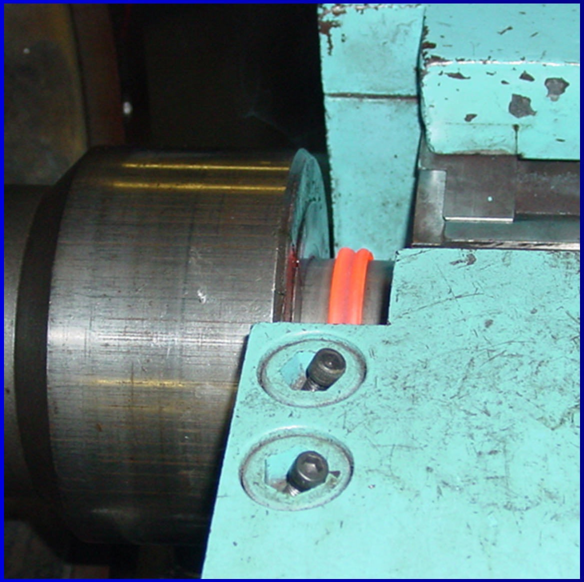
Inertia Welding: Process Variables



Inertia welding of MA956 tube butt joint

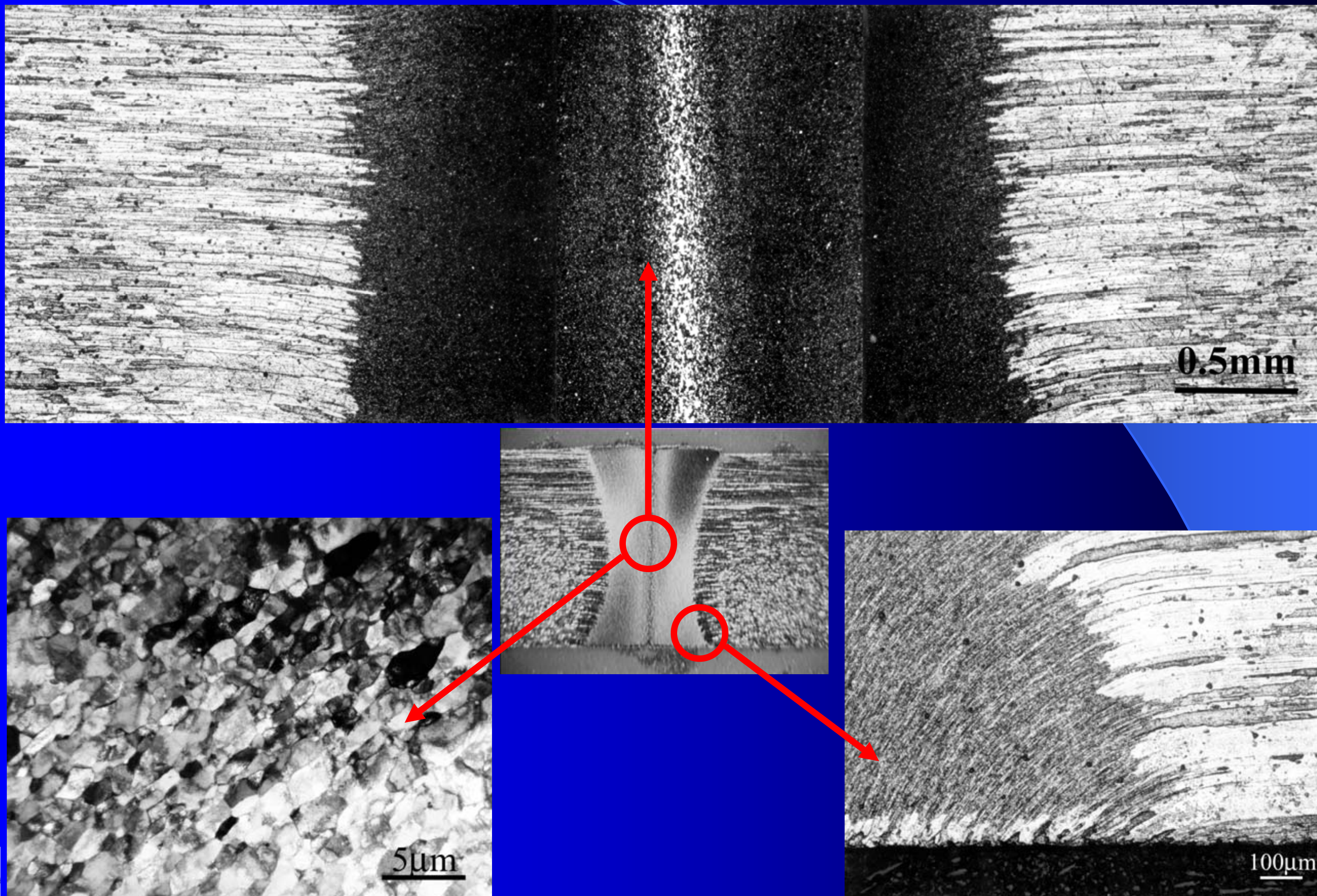
For heat exchanger fabrication configurations of 1) tube to tube, 2) tube to header block, and 3) tube to flange head are being explored for design development





Material Condition: 2-1/2” OD, ¼” wall thickness unrecrystallized MA-956 Tube

Inertia Welded Joint Microstructures



Evaluation of Inertia Welding Variables

No.	Inertia WK^2	Weld RPM	Energy Ft.lbs	Force lbs	Weld Upset
1	111.5	1500	42700	50K	0.153”
2	71.5	3000	110000	50K	0.498”
3	146.5	1000	25000	100K	0.125”
4	146.5	1500	56000	100K	0.360”
5	146.5	1700	72000	150K	0.490”
6	71.5	3000	110000	100K	0.662”

Energy (Ft.lbs) = Flywheel Inertial (Wk^2) x $(RPM)^2/5873$

Wk^2 Depends on Mass & Diameter of headstock & flywheel assembly

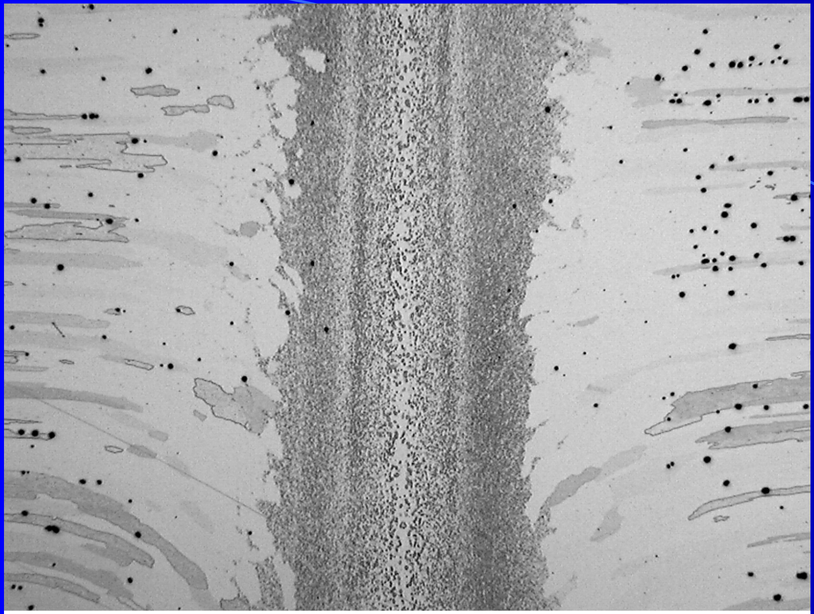
Inertia Welding Variables:

Flywheel Mass: 71.5 – 146.5

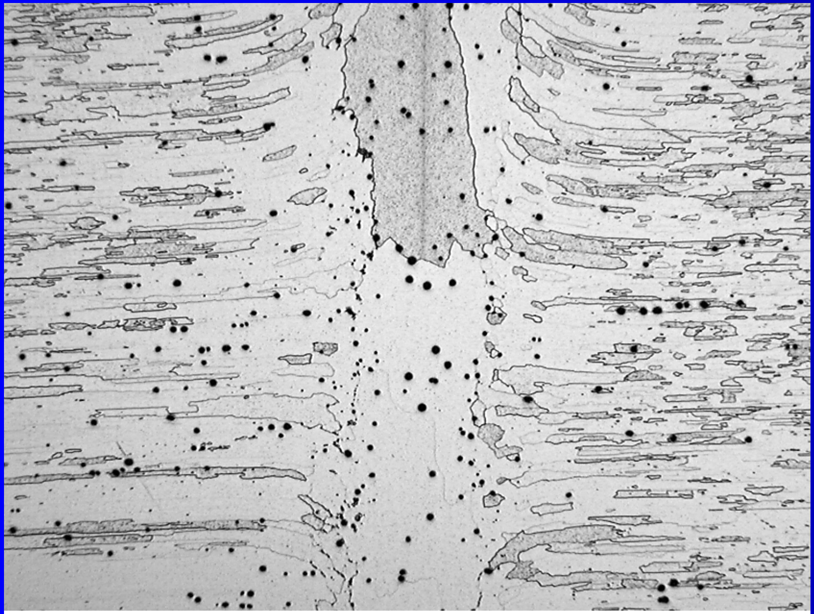
Weld Speed: 1000 – 3000

Weld Force: 50,000 – 150,000

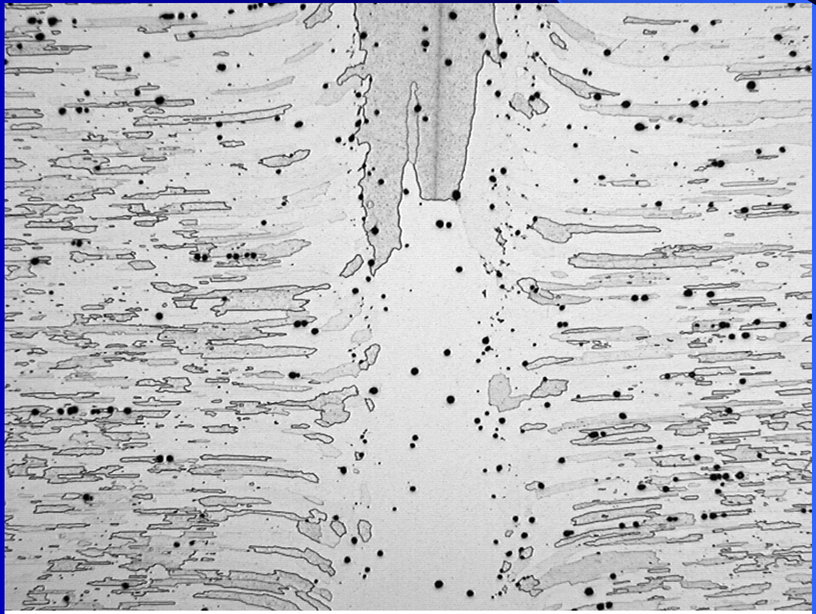
Weld Upset: 0.125” – 0.490”



#1 IFW 1 MA 956 HT 1375 50X 100μm

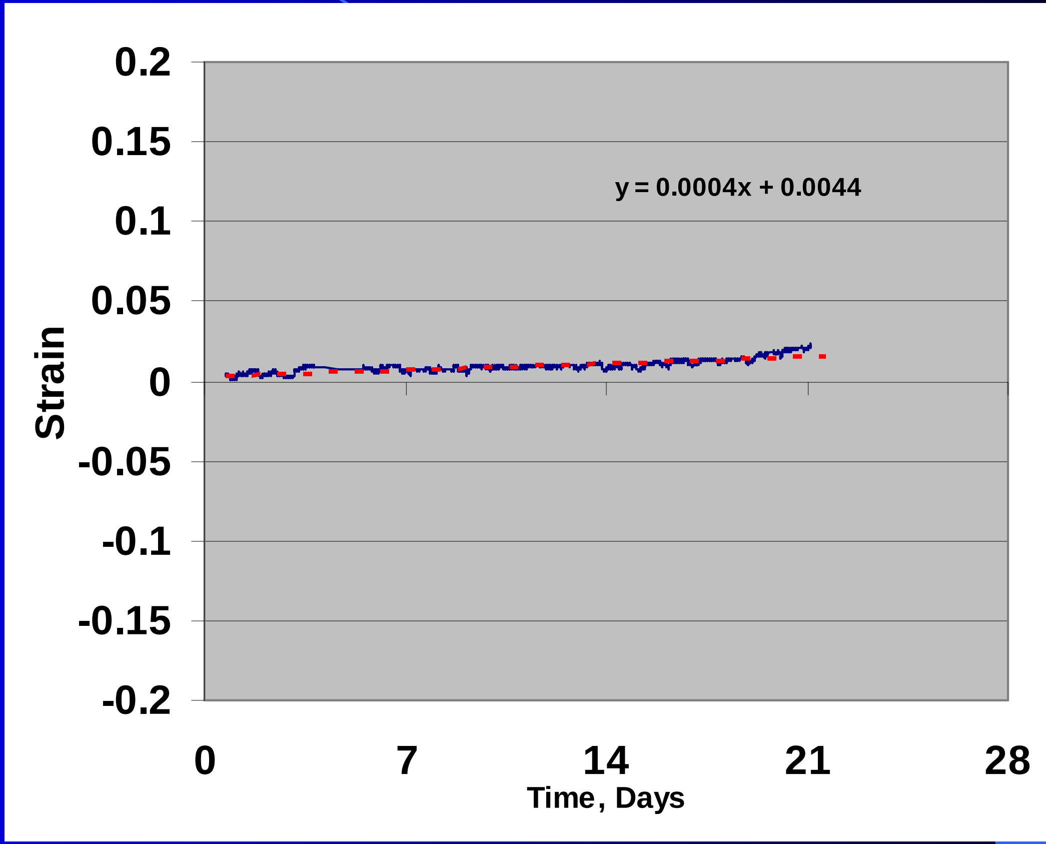


#3 IFW 3 MA 956 HT 1375 50X 100μm



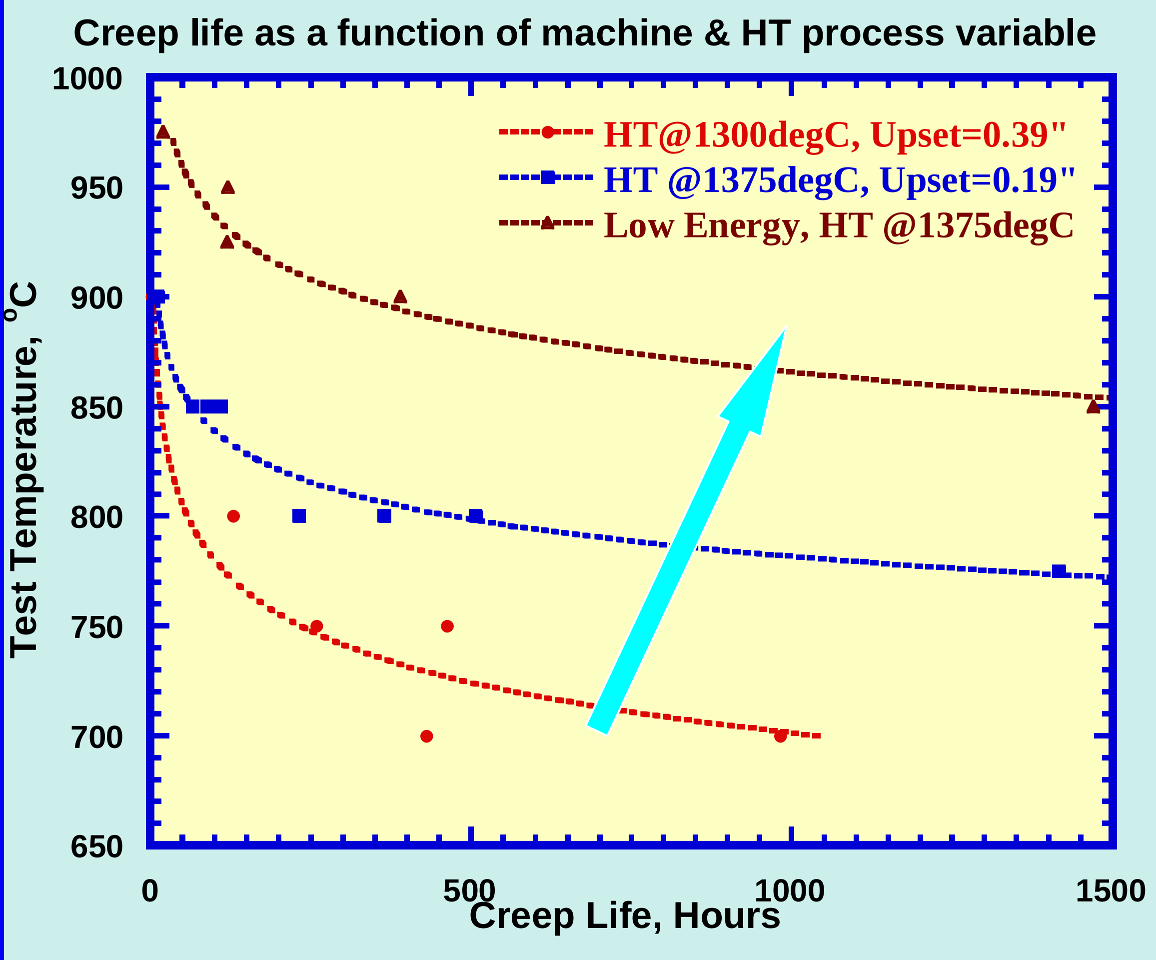
#5 IFW 4 MA 956 HT 1375 50X 100μm

High Temperature Creep Testing



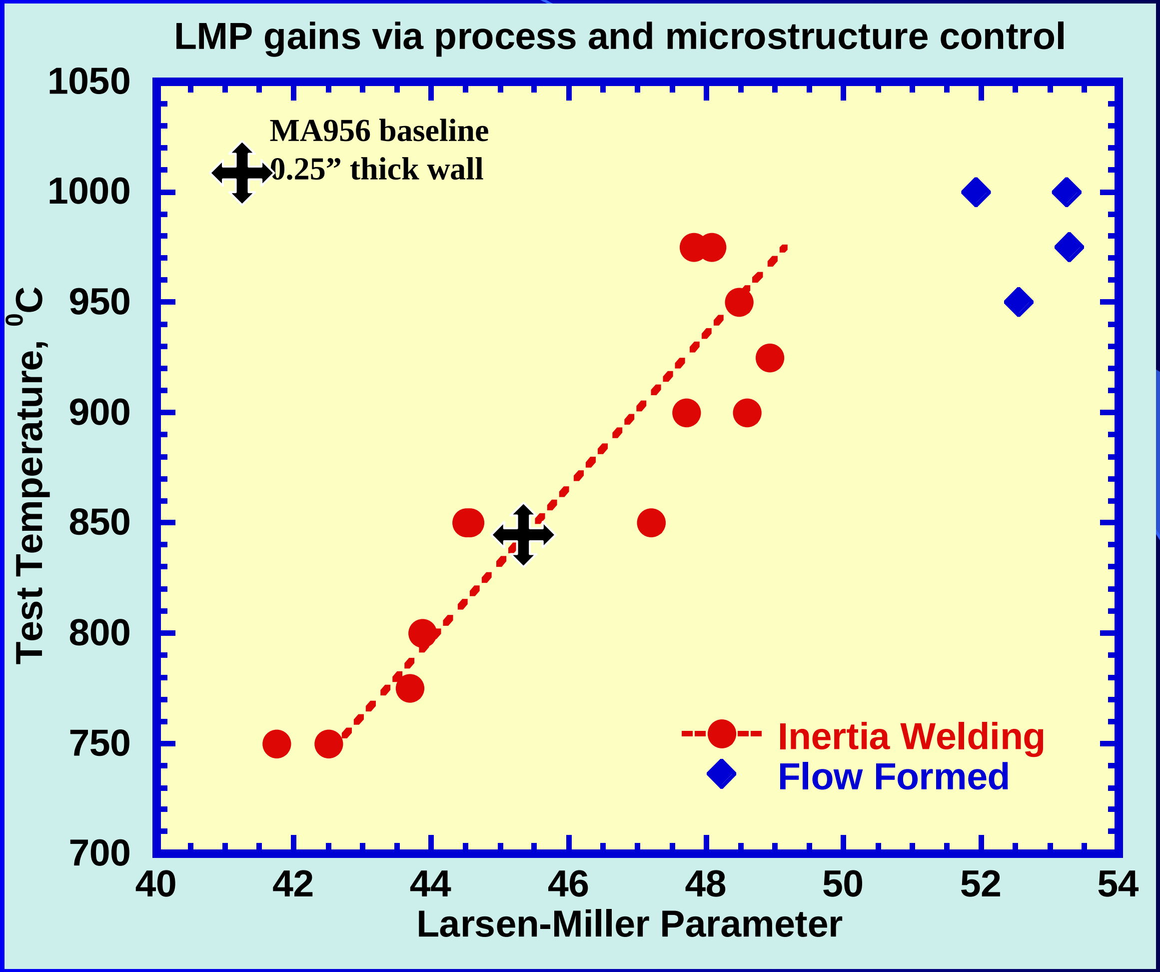
Creep behavior of MA956 butt joint. 900ºC test at 2Ksi stress. Steady state creep rate = 1.0e^{-4}/day is comparable to base alloy

Creep Enhancement via HAZ control, Inertia Welded Joint Microstructures



Significant creep enhancement is possible via control of machine variables

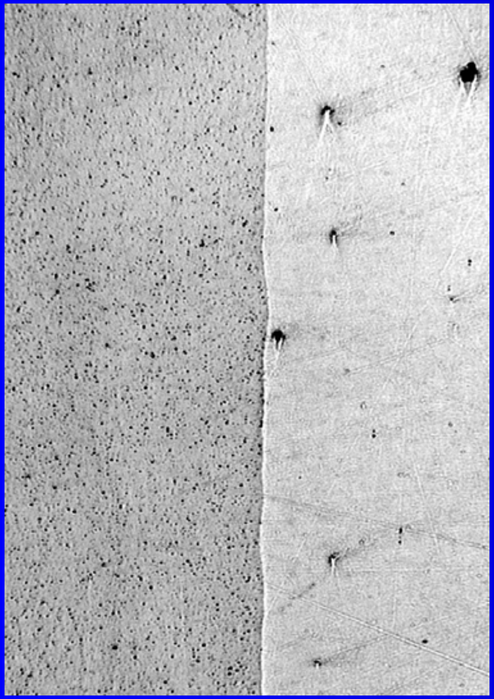
Status: Hoop Creep & Joint Performance



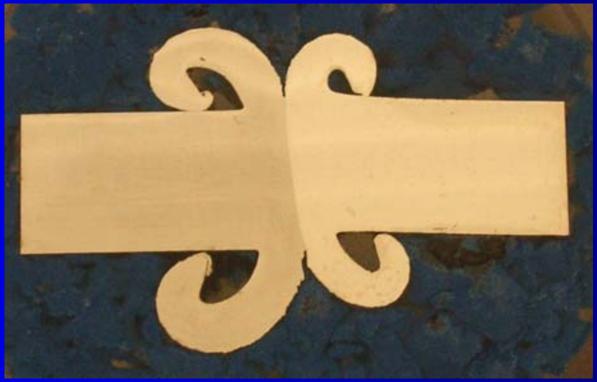
Composite of creep performance in MA956 inertia welded joints

Dissimilar IN601, IN617- MA956 Joining

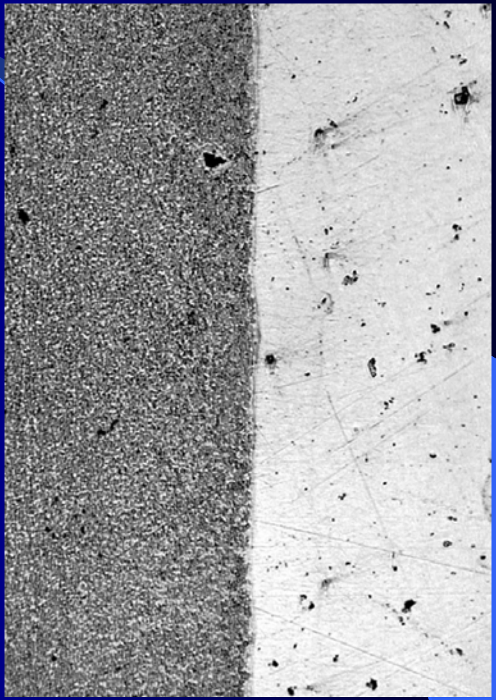
as-polished view



MA956 IN601



Etched view



Robust IN601-MA956 welds are produced with minimal process changes. Cross-section shows a smooth interface with asymmetric material flow across the interface.

Summary of Results

- Inertia welding joining methods are being developed for butt joint configurations.
  maturing development for MA956
- Process variables very important – but once developed can easily be ported to the field.
- Similar and dissimilar alloy joints fabricated
- Precipitate strengthened IN740 joints pending
  issue with initial microstructure & PWHT