Microstructures and High Temperature Performance of ODS Alloy Non Fusion Joints

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ODS 2010 Workshop
November 17th – 18th 2008, UCSD, La Jolla, CA

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*
- *ODS alloys have issues with fusion based joining*
- *ODS alloys have dispersoid segregation issues*
- *Component fabrication efforts are predicated on devising viable enabling joining methodologies.*

Sample Non-Fusion Joints in MA956

Inertia Weld (UCSD)

Magnetic Pulse (UCSD)

Flash Upset (EWI)

Inertia welding is the best performer. Flash Upset works as well.

- Non-fusion joining techniques
  - *Magnetic pulse welding: lap joint configurations*
  - *Inertial welding: butt joint configurations*

Presentation Outline

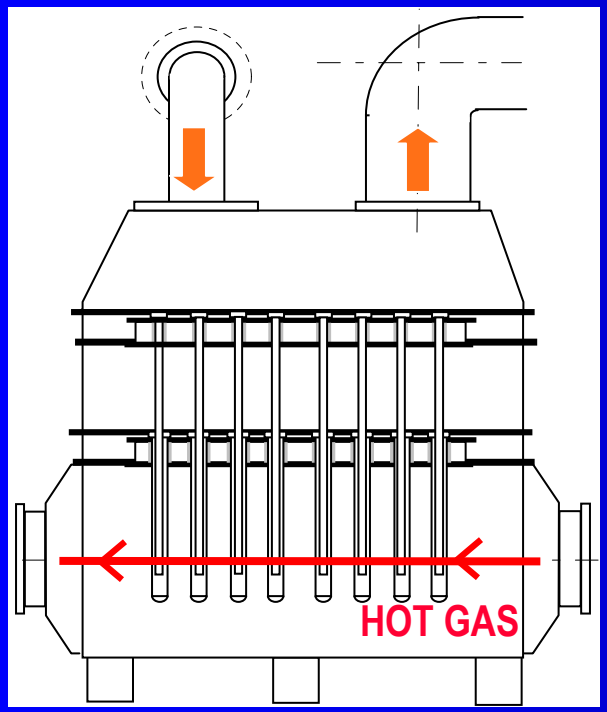
Experimental Configurations & Particulars

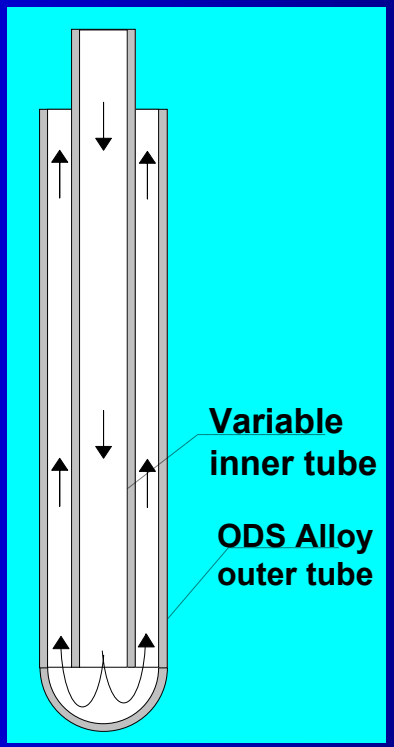
Progress Till Date: Two Process Iterations

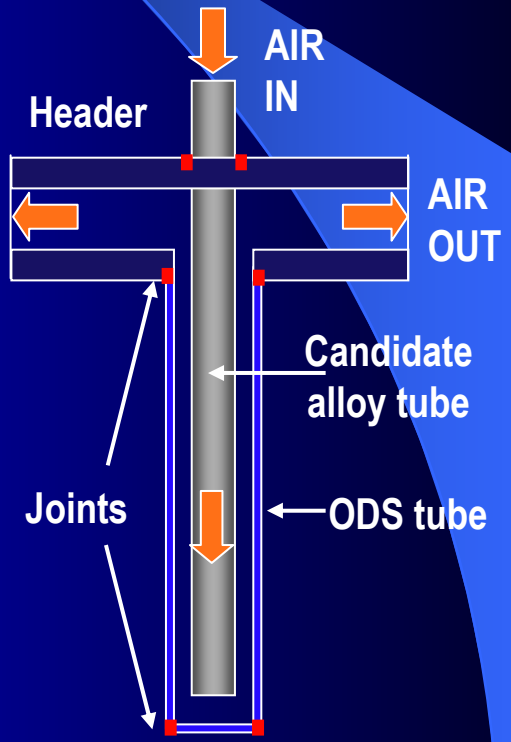
- *Inertia welding: butt joint configurations*
  - *Similar Metal/ ODS Alloy Joints*
  - *Dissimilar Metal/Alloy Joints*

Design Issues and Projected Joints for High Temperature Heat Exchanger (HTHE)

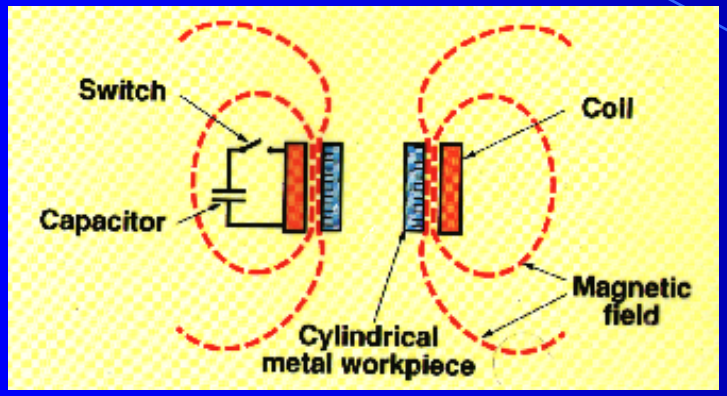
Bayonet Tube Design: one free end; stress reduction
HTHE Prototype, Pressurized, 40 tubes, 2"OD, 40" long
Source: UK Cost 522 Program

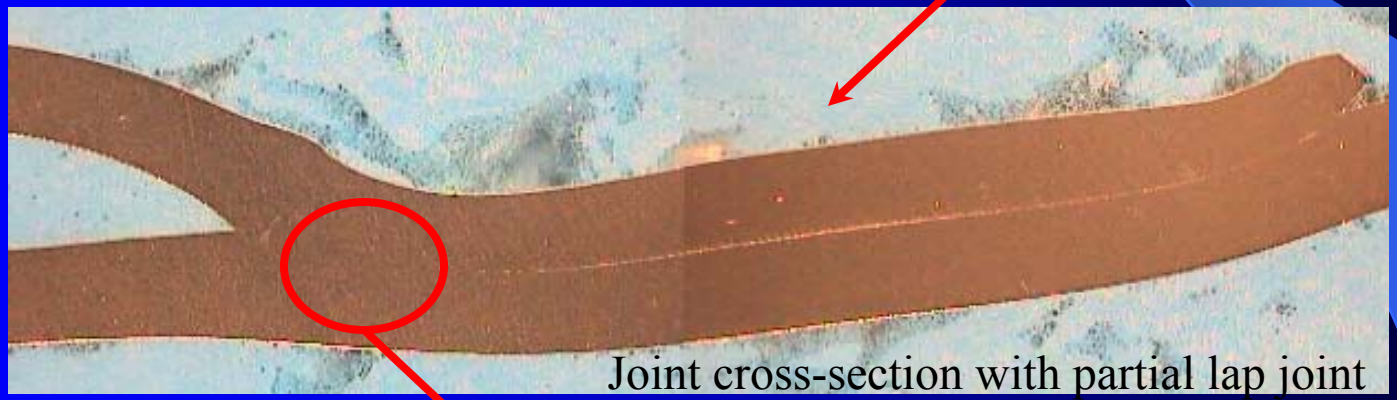




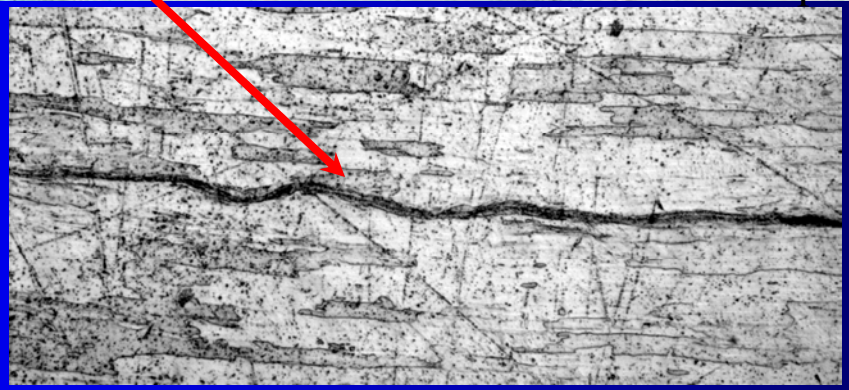


Magnetic Pulse Joining: Tube Lap Joint Integrity Evaluation

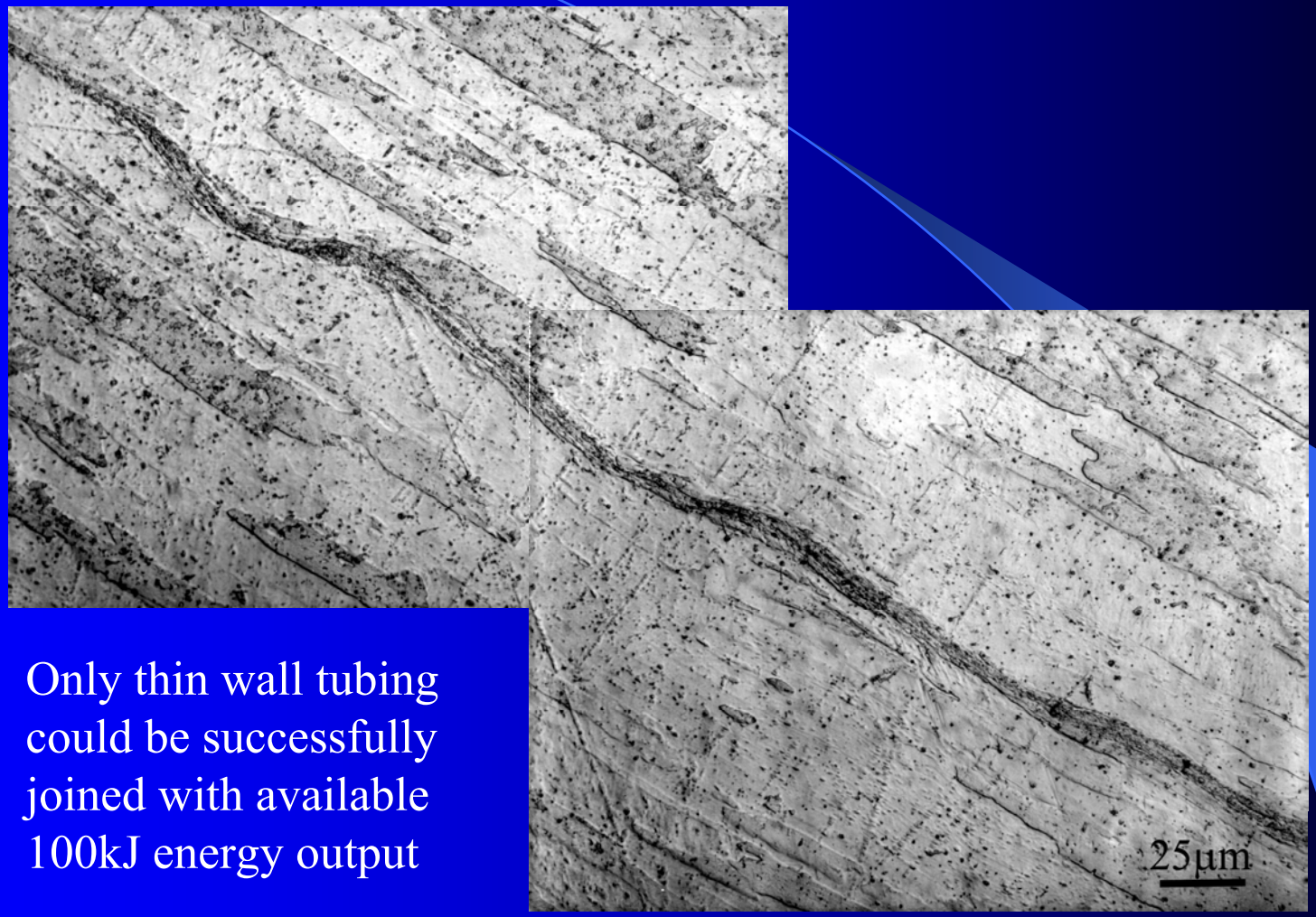




Joint cross-section with partial lap joint



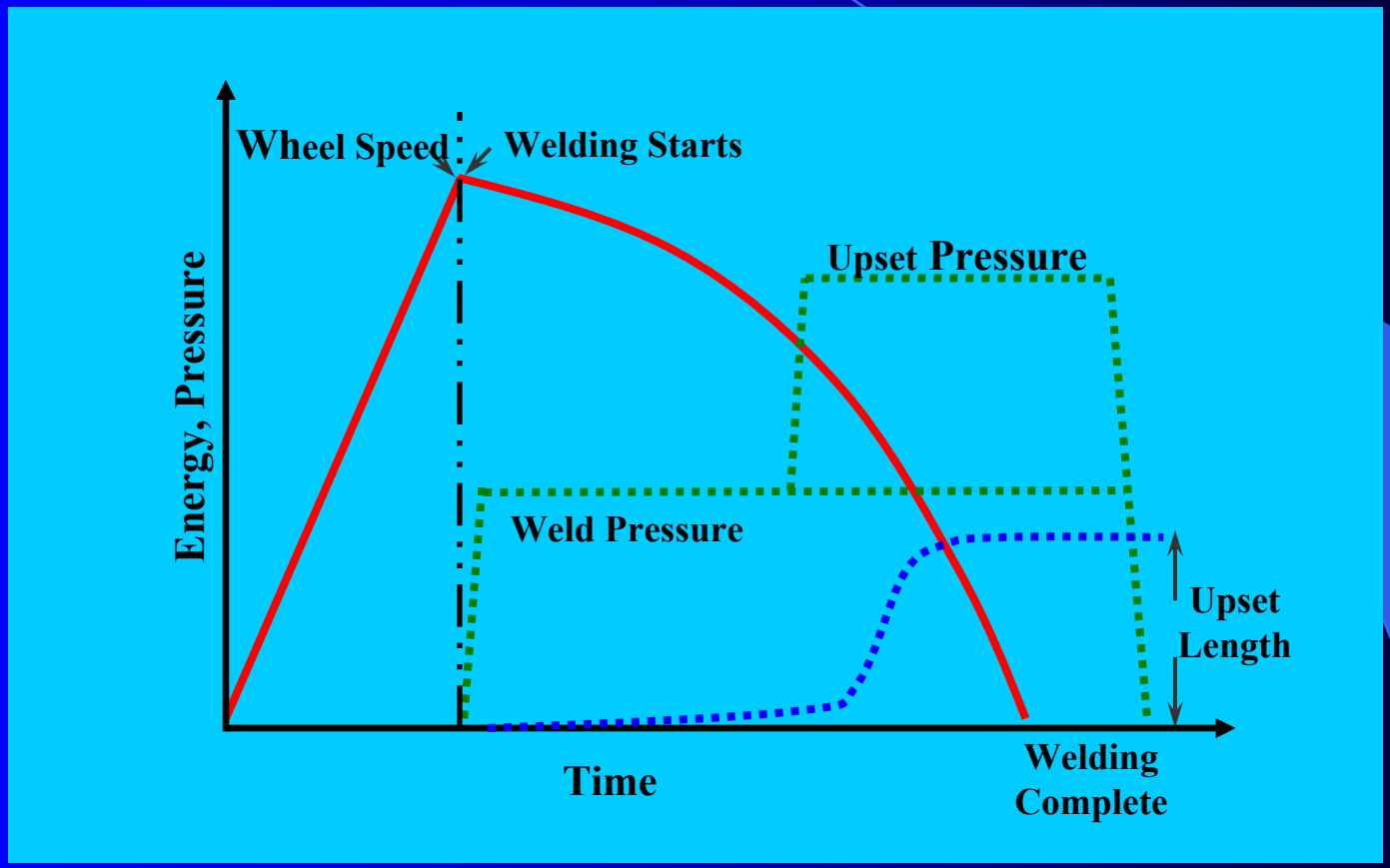
Microstructural Integrity of MPW Joint



Only thin wall tubing could be successfully joined with available 100kJ energy output

Cold worked joint with re-crystallized MA956 tubes.
Process Benefit: No Post Weld HT required

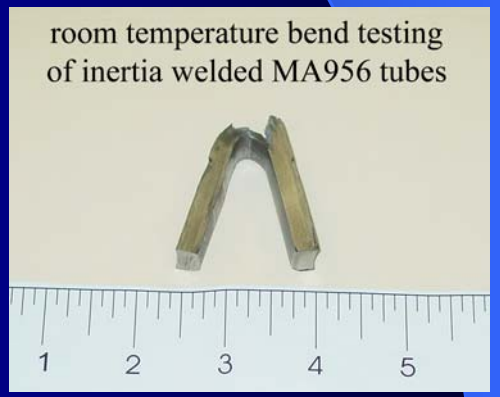
Inertia Welding Techniques: Process Variables



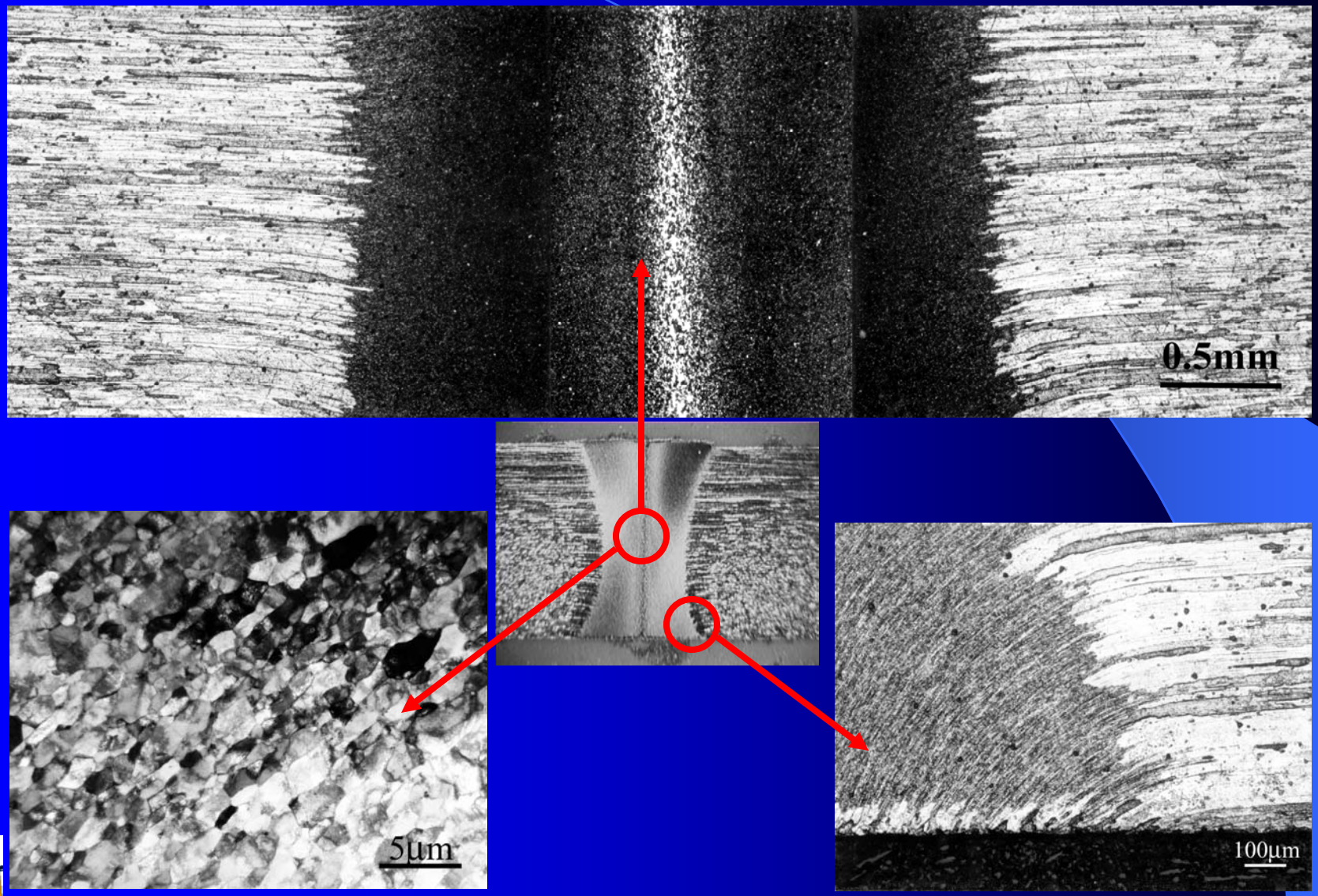
Process available as single stage (constant weld pressure) or double stage (variable upset pressure)

Inertia welding of MA-956 tubes

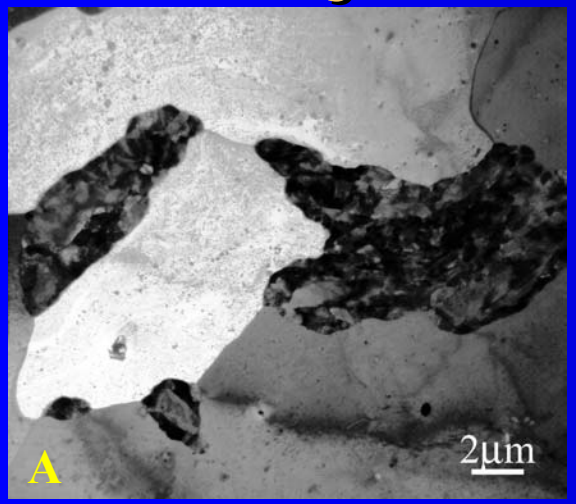
Mechanically robust joints can be produced in ODS-MA956 alloy tubes via inertia welding. Initial process window for reproducible tube joints ascertained via the integrity of the joint in bend tests in coupons cut from joined tubes. Material condition: 2-1/2” OD, ¼” wall thickness un-recrystallized MA-956 Tube



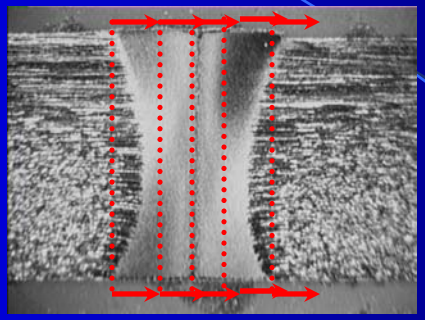
Inertia Welded Joint Microstructures



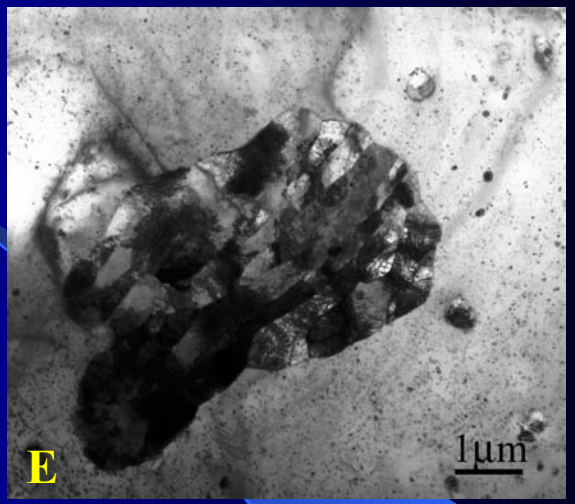
Recrystallized Joint Microstructures

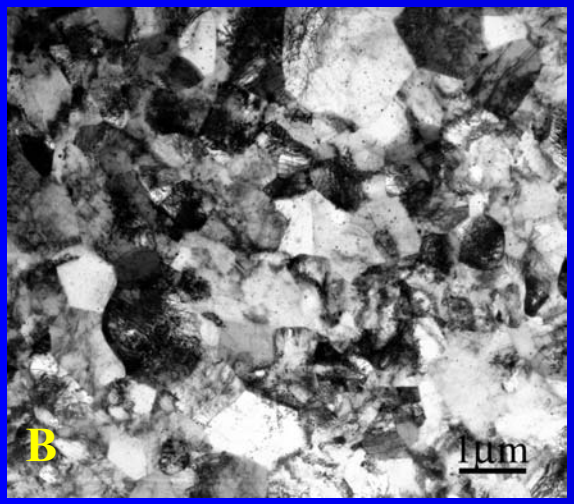


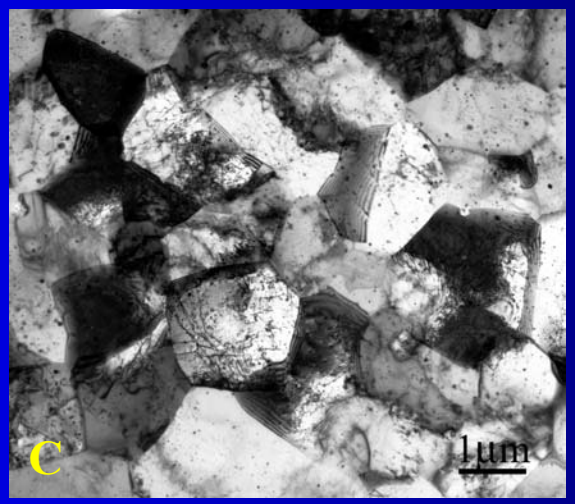
Cross-Sectional Views

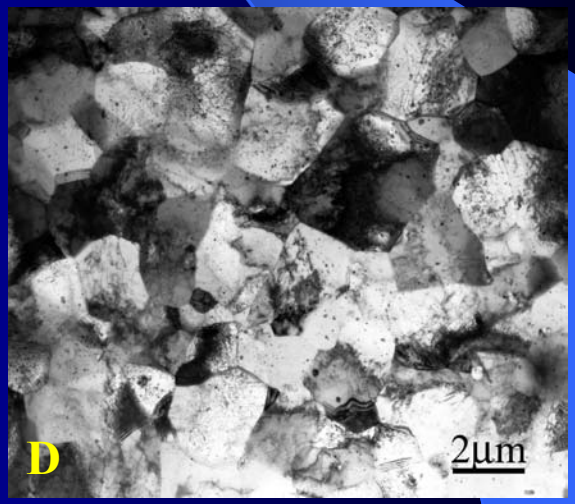


A B C D E



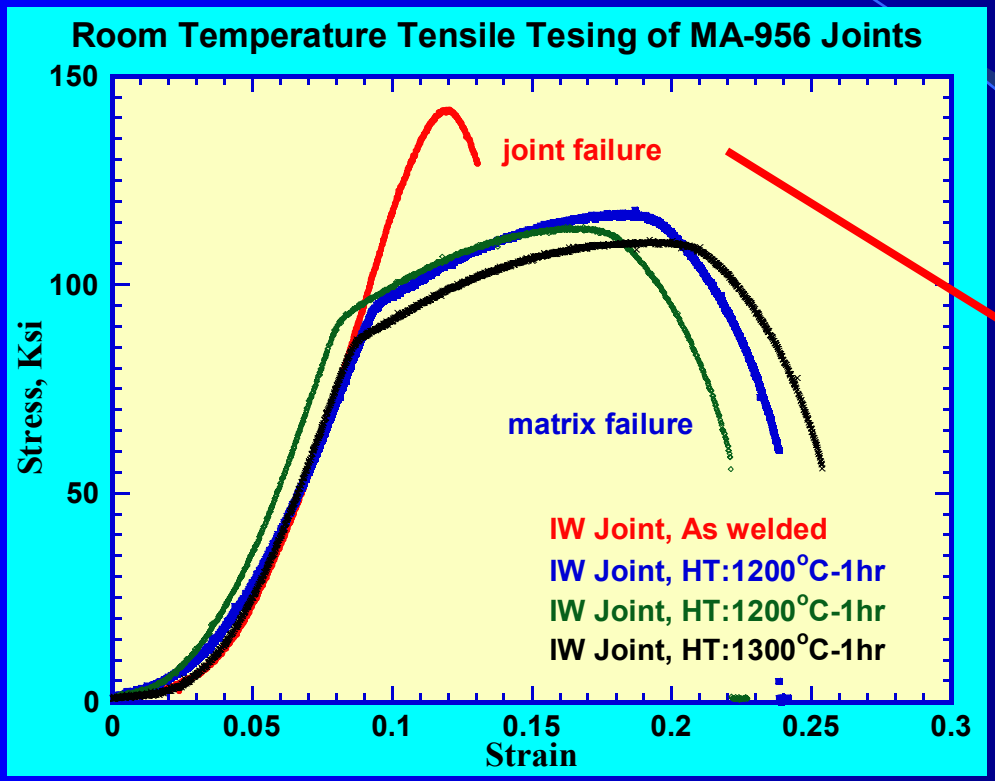


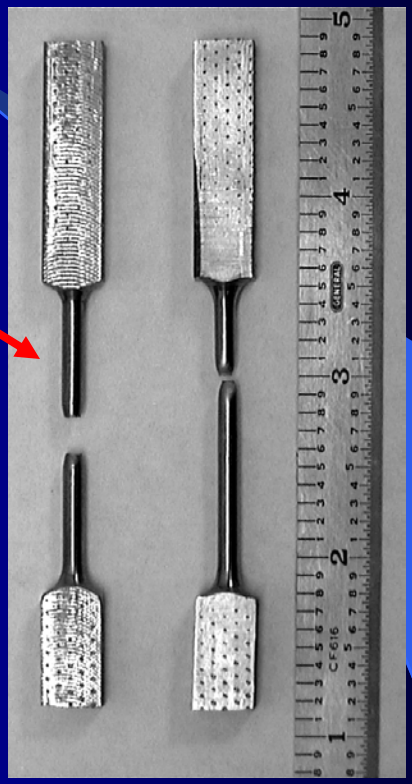




MA956 Joint recrystallized at 1200°C-1hr in air. Anti-clock wise from top left: a cross sectional view of the recrystallized structure. View A, E reveal partial recrystallization of the deformed HAZ region at the periphery.

Inertia Welded Joint Integrity: Room Temperature Test Results

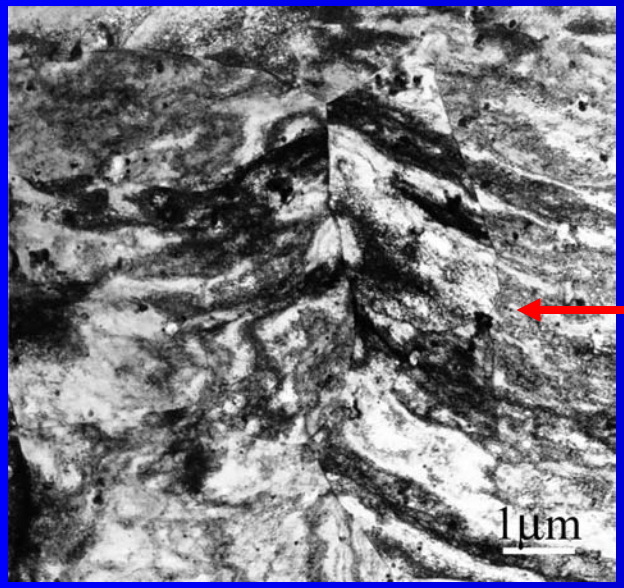




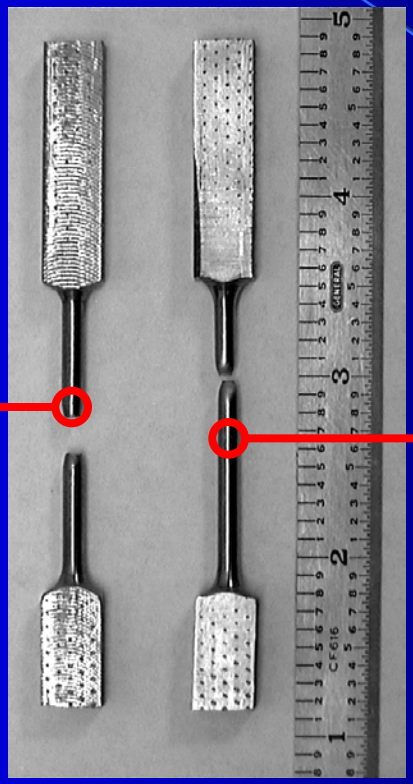
In as-welded condition: joint fails at about 90% of the unrecrystallized matrix strength. In the re-crystallized condition: joint is far superior than the matrix.

Joint Deformation and Failure

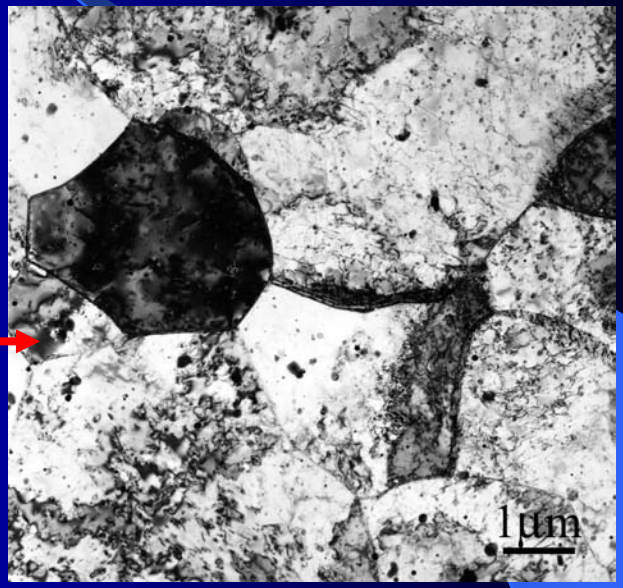
As-welded, RT tensile test



Cross-sectional view



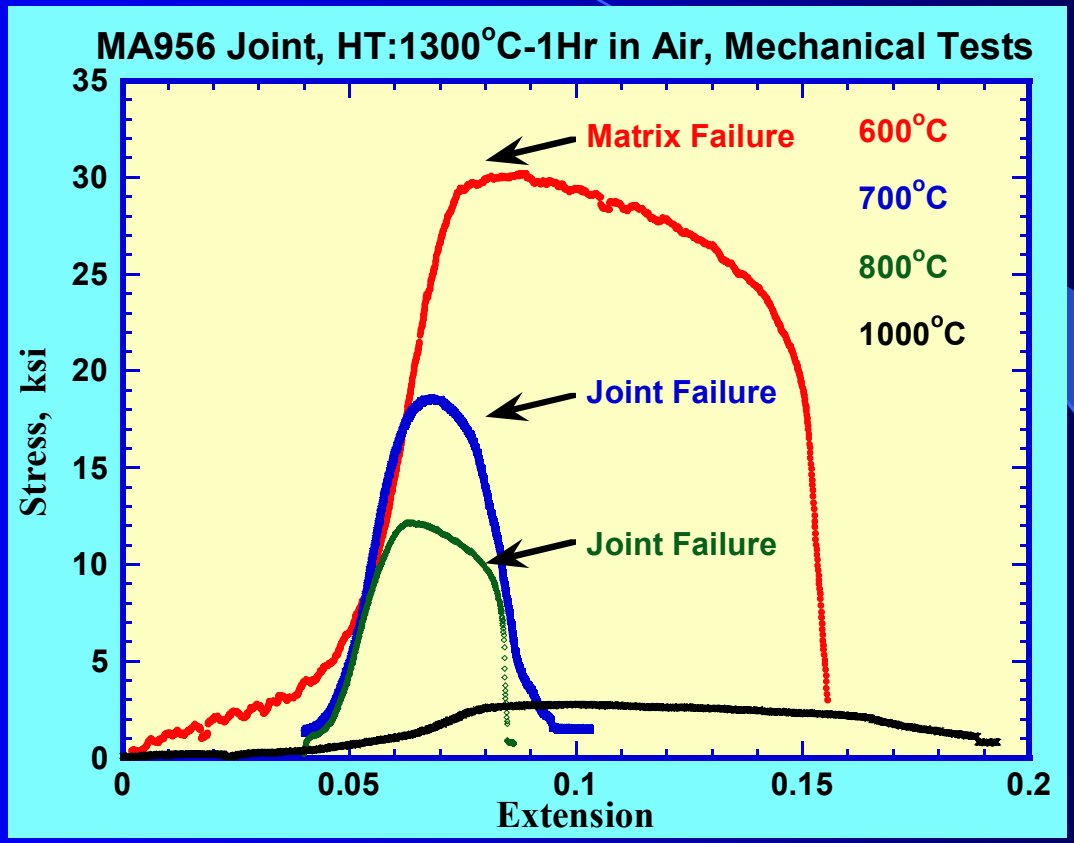
HT:1200°C-1hr, RT tensile test



Cross-sectional view

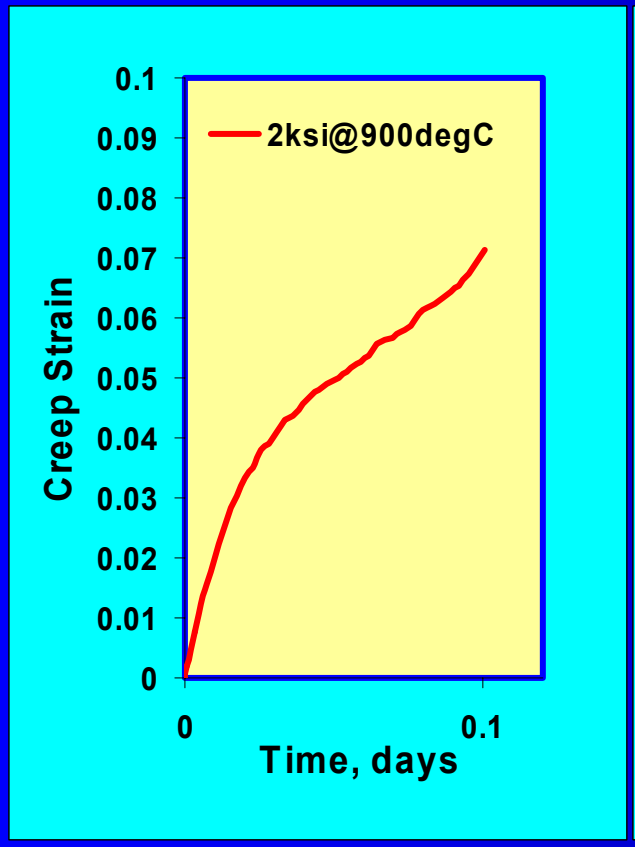
As-welded: joint fails with severe deformation bands. Traces of grain flow suggests failure away from interface. Heat-treated condition: Joint region has the nominal deformation/dislocation activity.

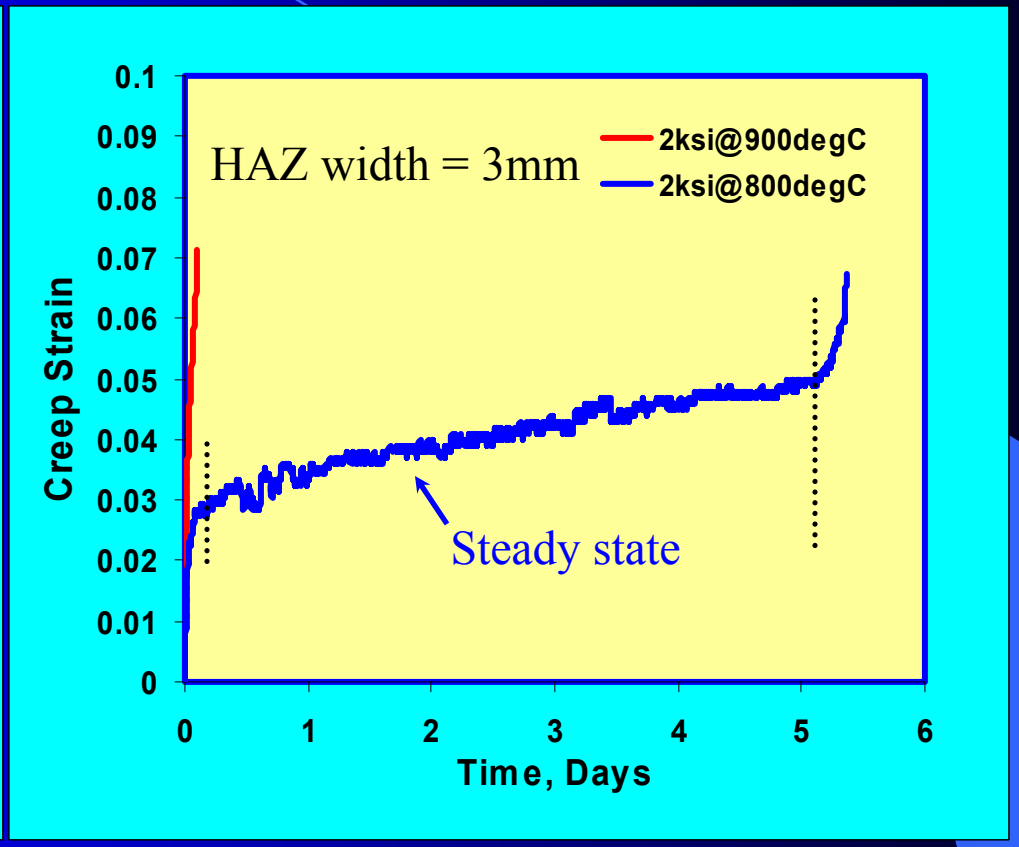
High Temperature Longitudinal Response



Joint sections heat-treated at 1300°C –1hr in air. Longitudinal joint sections tested for high temperature integrity. At 600°C and below failure occurs in the recrystallized matrix. At 700°C and above failure occurs in the joint regions.

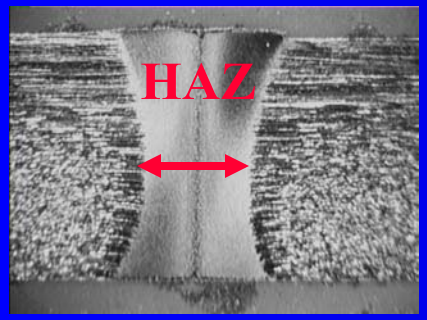
Longitudinal Creep Test Response





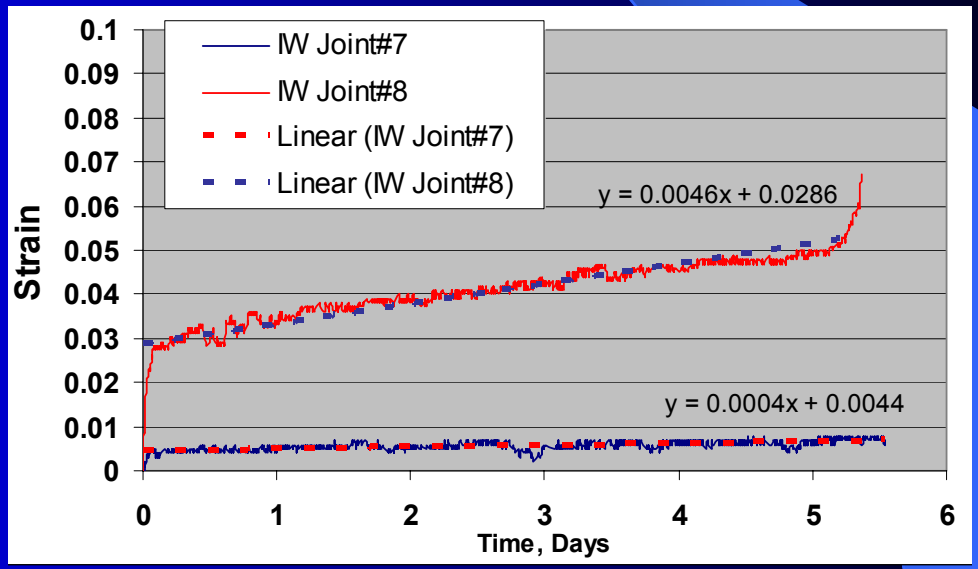
Longitudinal joint sections heat-treated in air at 1300°C –1hr and creep tested in air. Coupons exhibit the primary, steady state and tertiary regimes. Failure occurs in the joint region.

Inertia Welded Joint: Creep Response



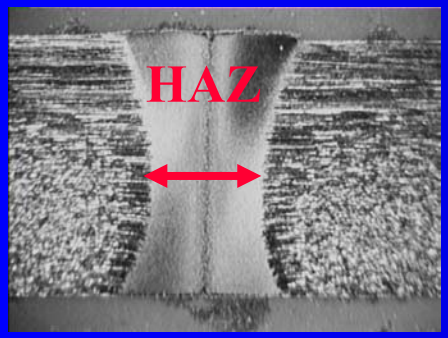
The width of the heat affected zone (HAZ) as dictated by the inertia weld energy input and the extent of the forge upset influence creep response. Lower energy and smaller upsets yield improved creep response.

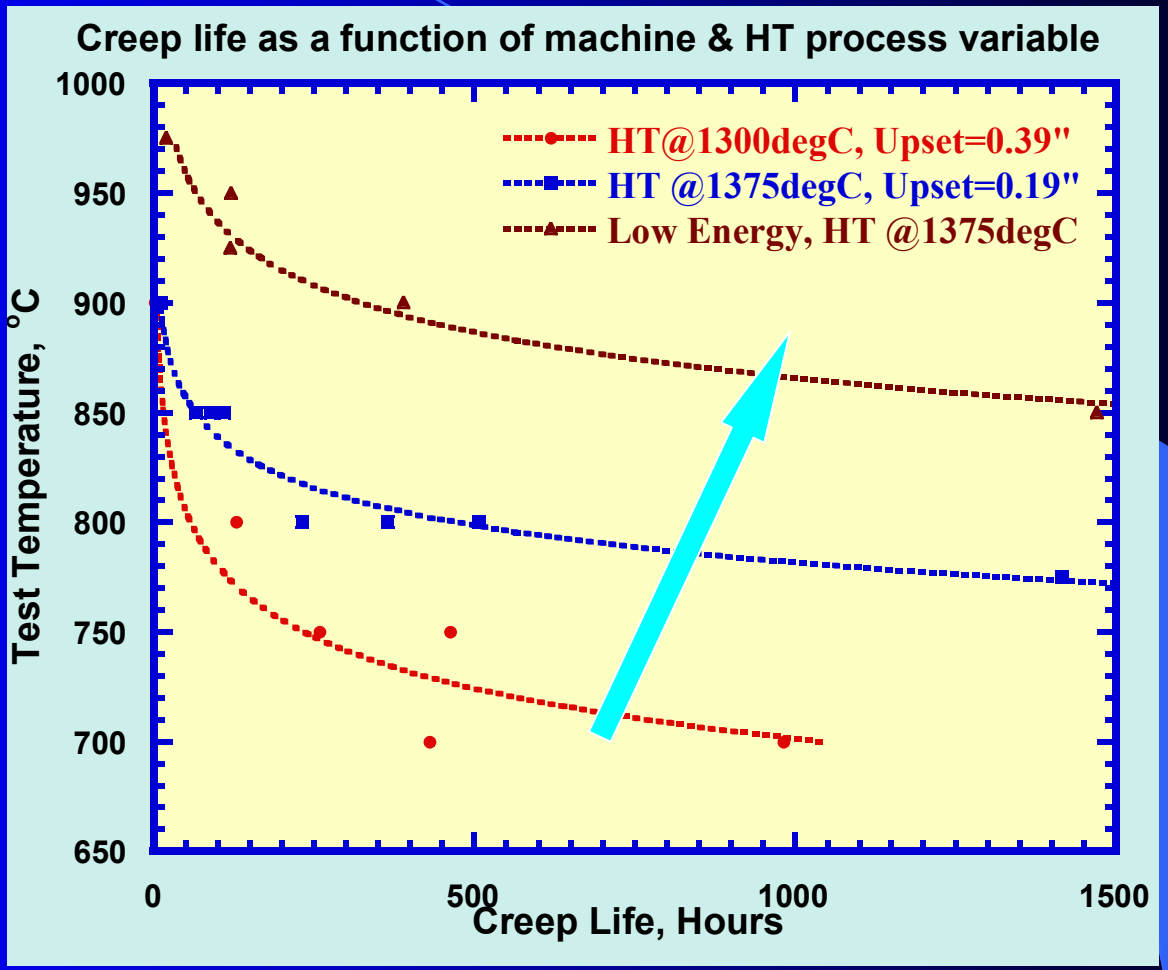
Sample	IW#7	IW#8
IW upset	0.195”	0.343”
HAZ	1-1.5mm	2.5-3mm
Creep rate	$4x10^{-4}$	$4.6x10^{-3}$
Creep strain	<1%	4%
L-M Para	44.37	42.72



Longitudinal joint sections: HT: in air at 1300-1375ºC –1hr and creep tested in air.

Creep Enhancement via HAZ control of Inertia Welded Joint Microstructures





Creep enhancement possible via control of machine variables

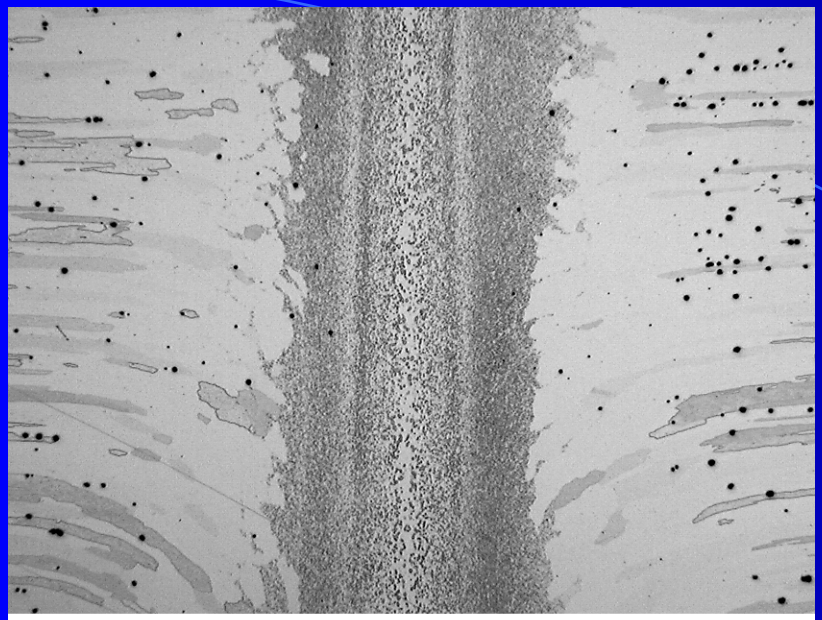
Evaluation of Inertia Welding Variables
2nd Iteration

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

NO



Inertia Welding Variables:

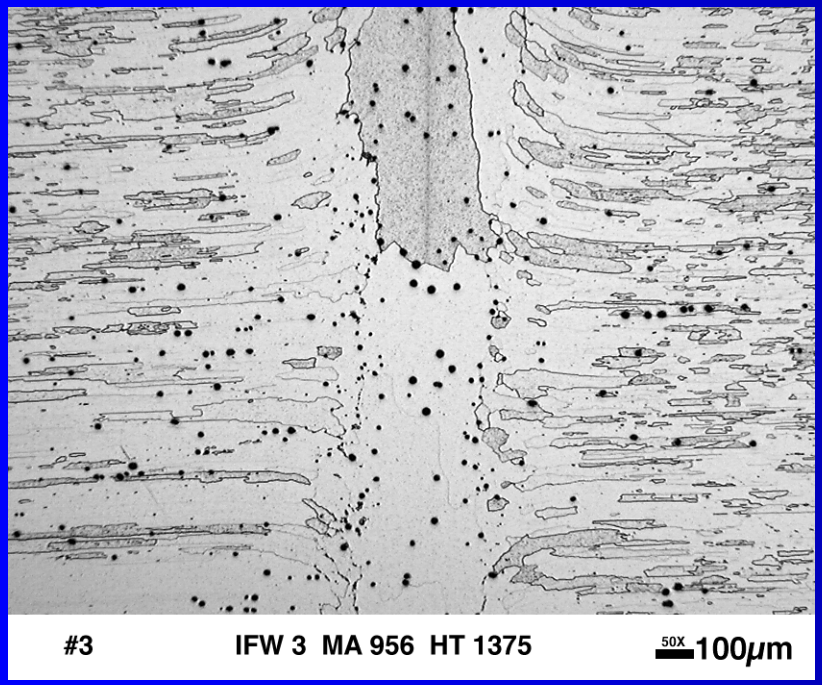
Flywheel Mass: 71.5 – 146.5

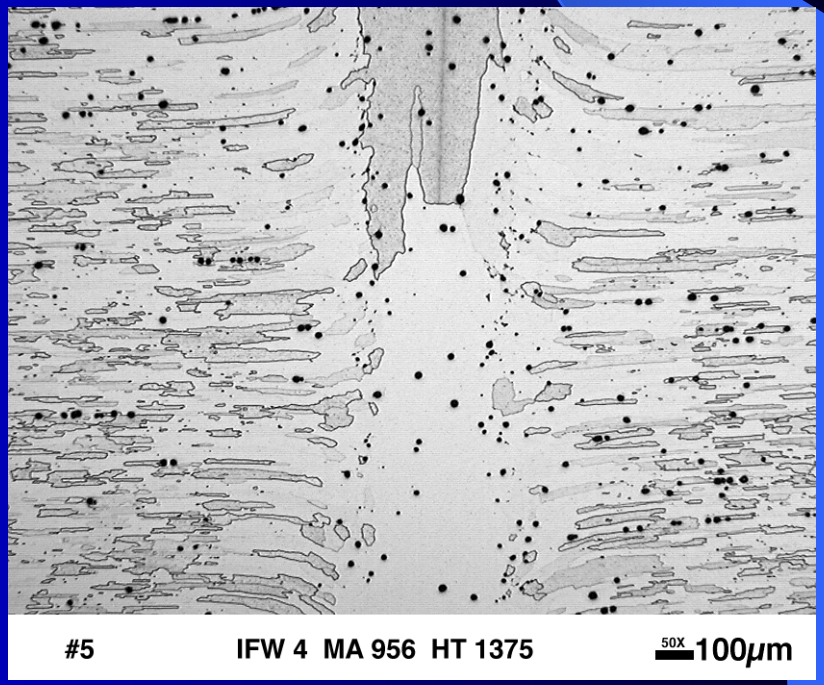
Weld Speed: 1000 – 3000

Weld Force: 50,000 – 150,000

Weld Upset: 0.125” – 0.490”

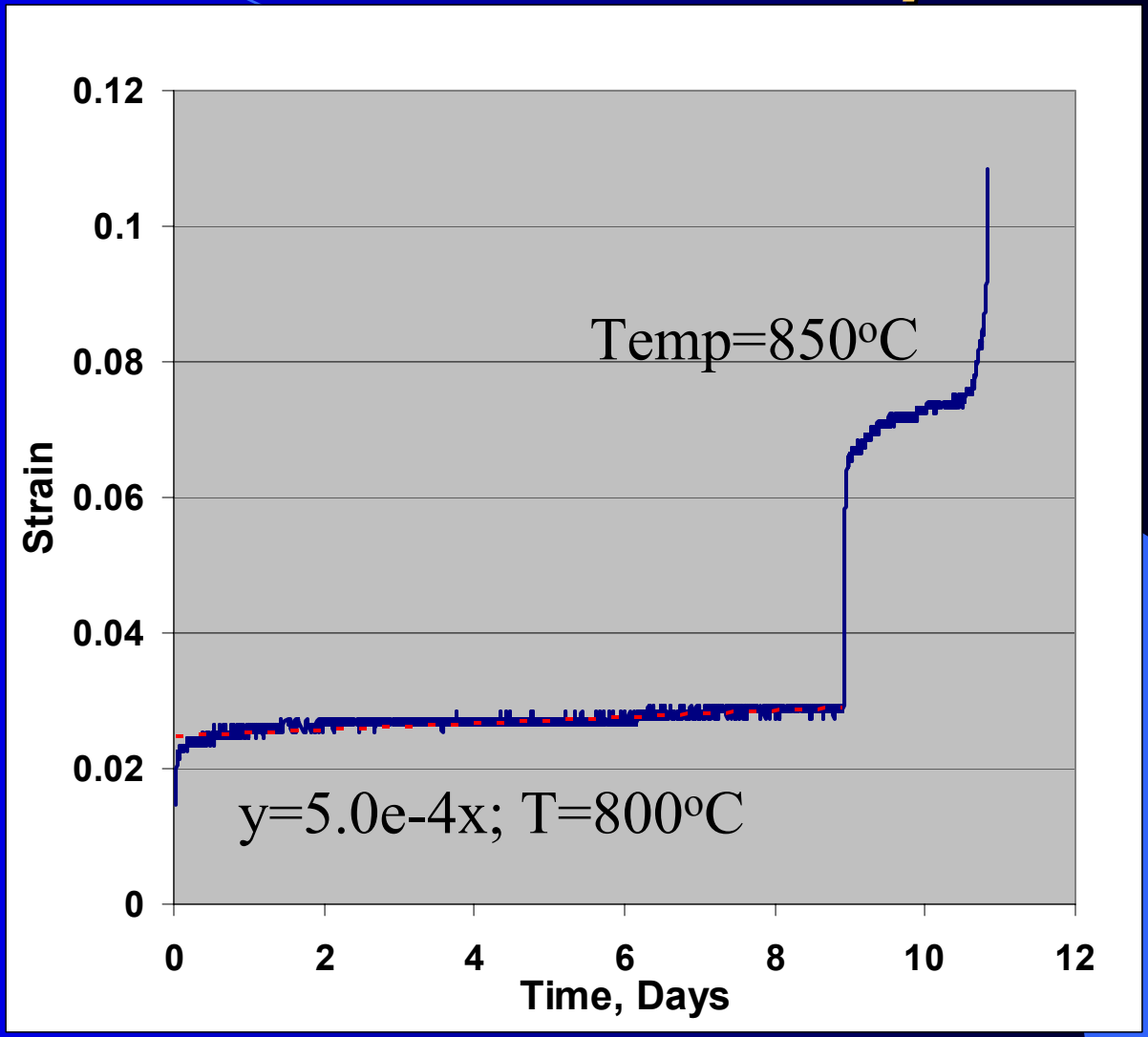
OK





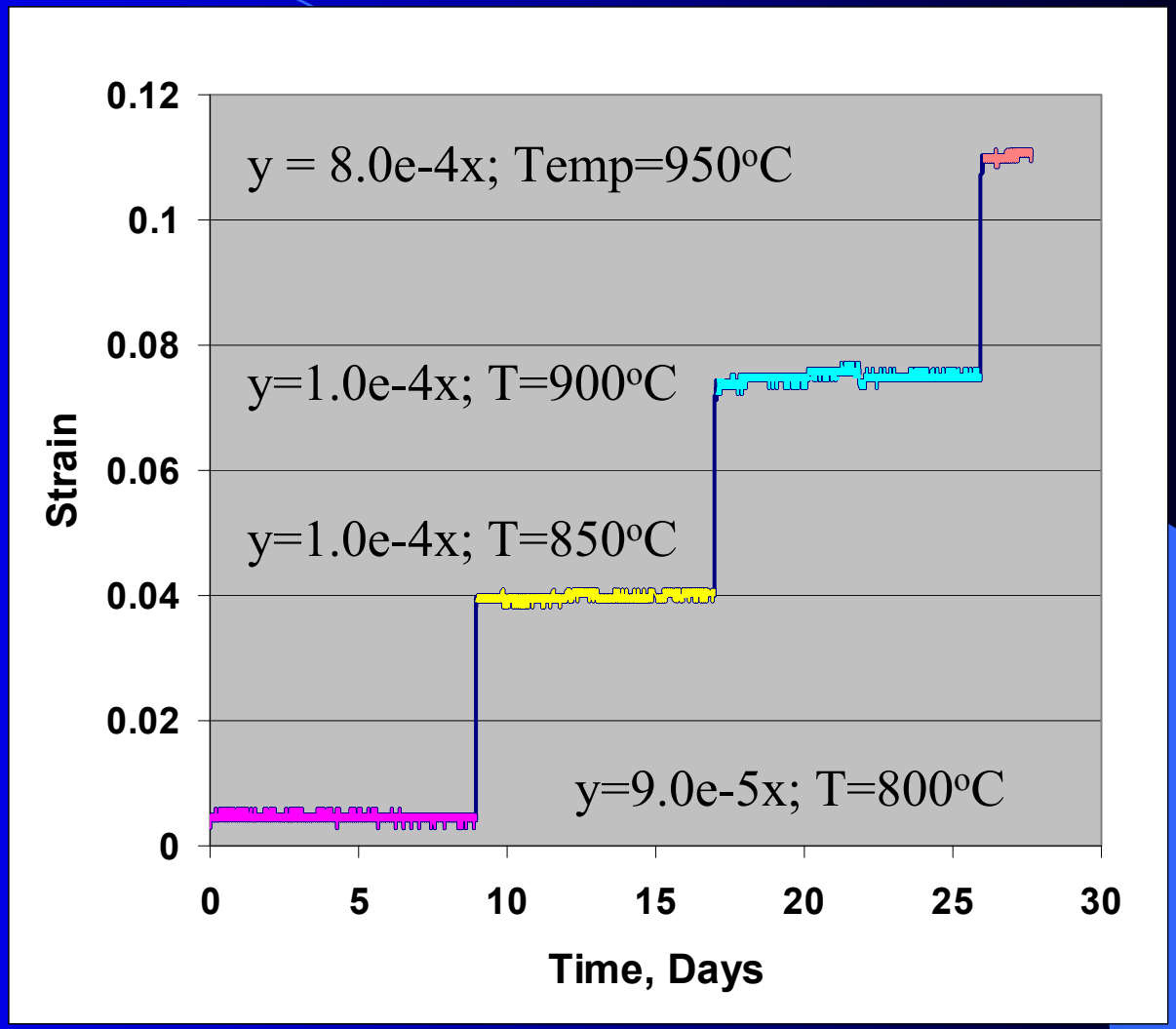
OK

MA956 Temperature Increment Creep Test



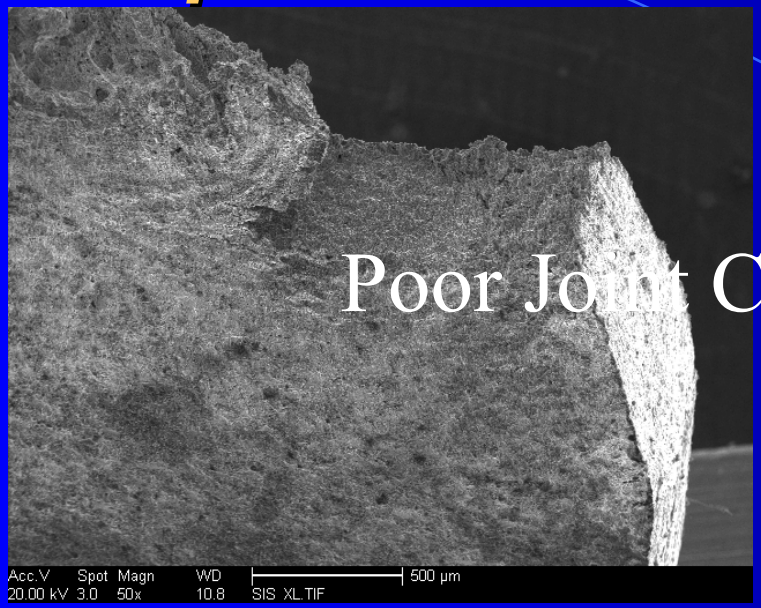
Joint #1, 2ksi Stress, Test in Air, Poor

MA956 Temperature Increment Creep Test

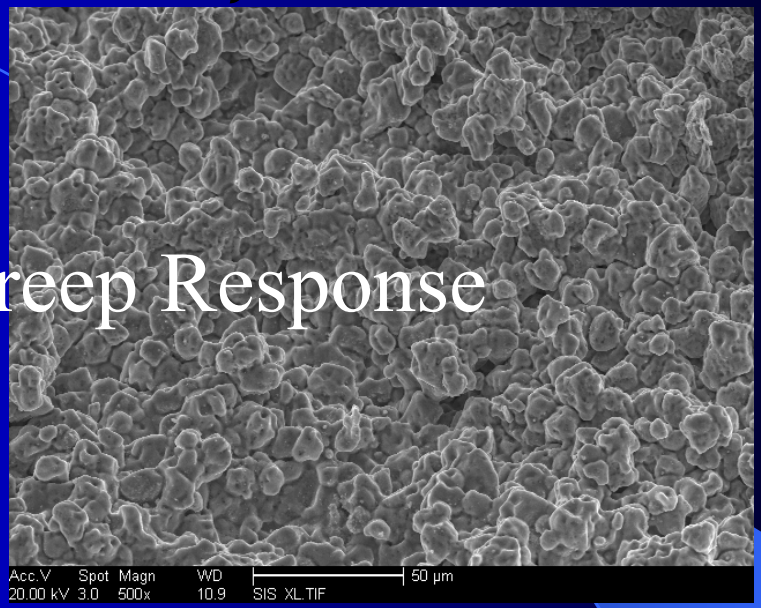


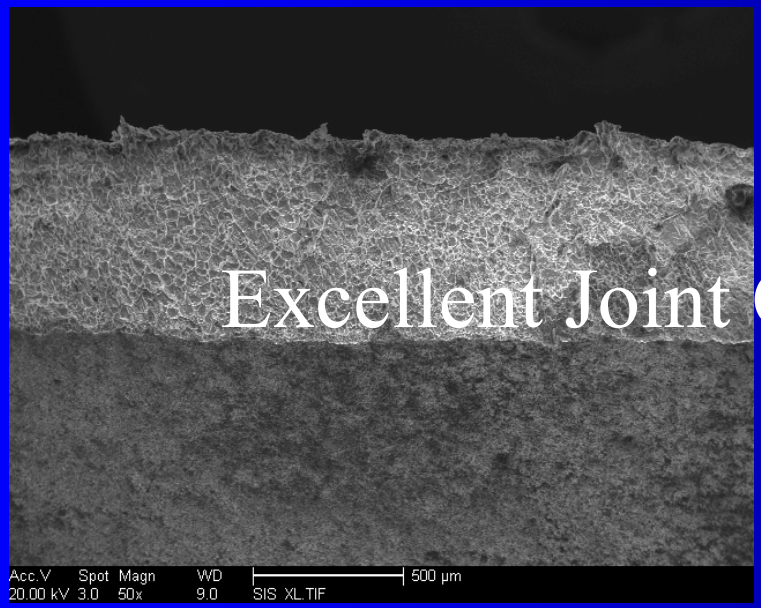
Joint #3, 2ksi Stress, Test in Air, OK

Creep Fracture Evidence, Good & Bad

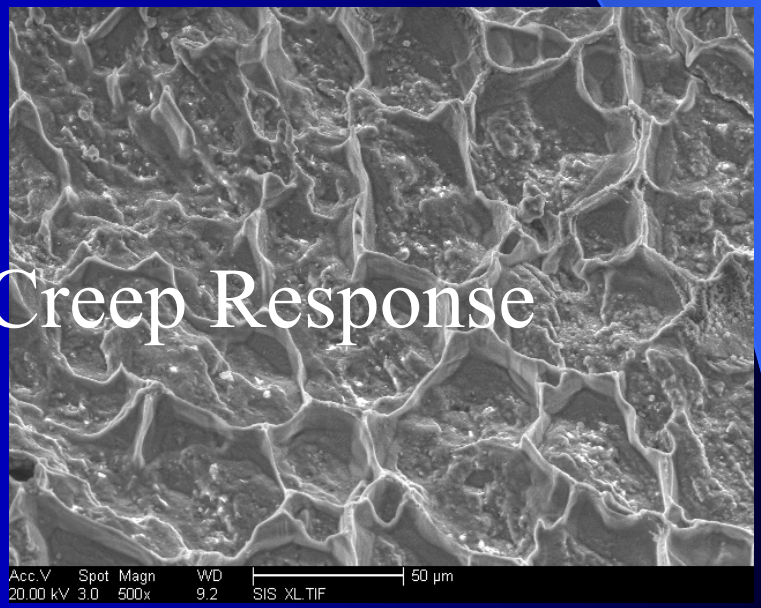


Poor Joint Creep Response





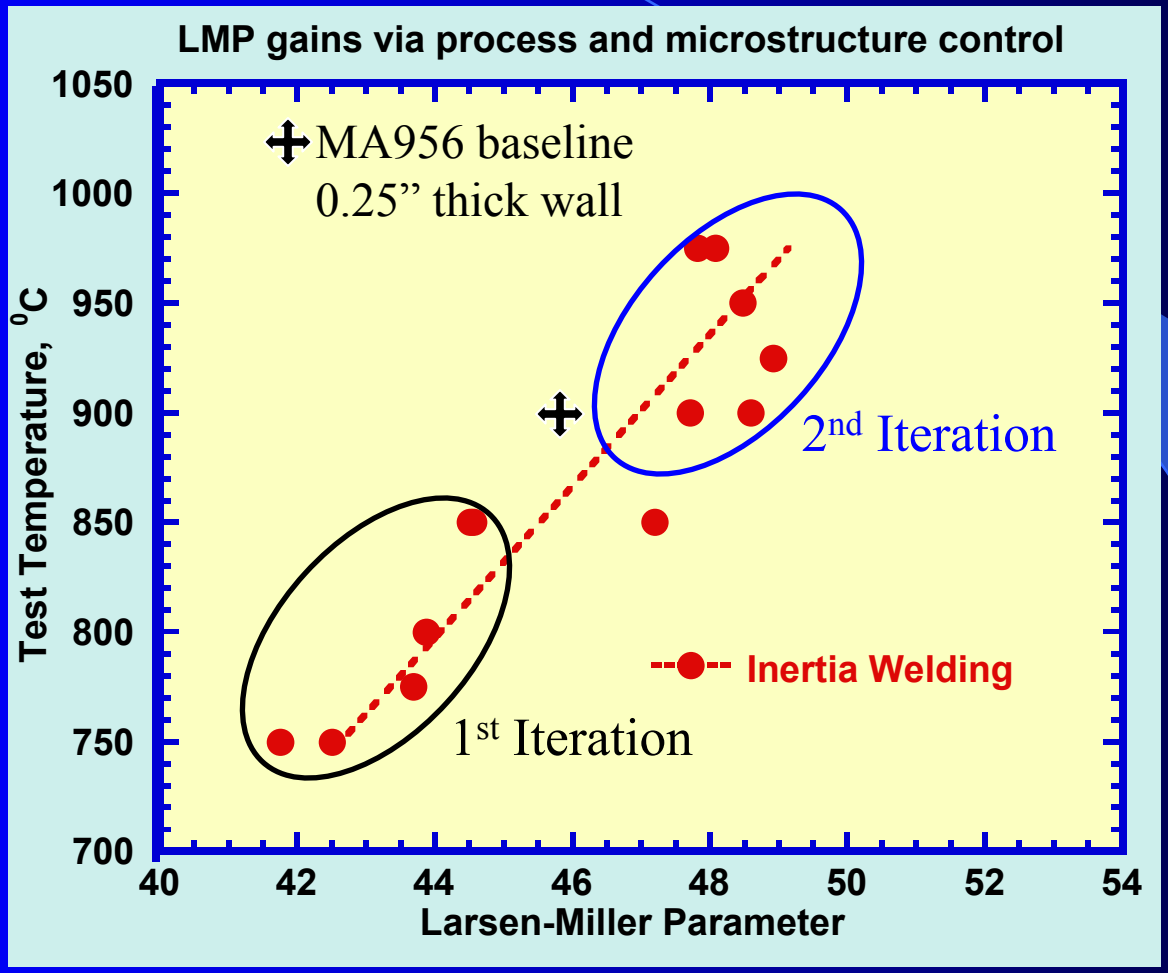
Excellent Joint Creep Response



Status: Inertia Welded Joint Performance

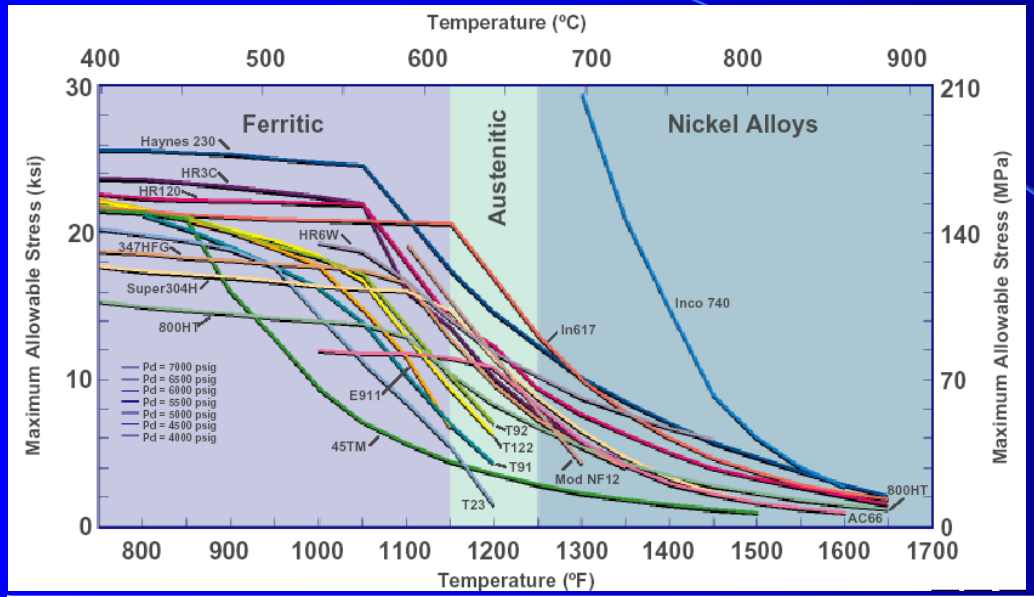
	MA956 Joint Processing and HT	Temp °C	Stress, Ksi	Life, Hrs	LMP	Strain, rate/day
1	MA956, As-received, 1375°C,1hr, Air	900	2		46.09	
2	Flash Upset, HT:1375°C, 12hr, Air	850	2	144	44.80	6.0e-4
3	Inertia Weld, HT 1375°C, 12hr, Air	850	2	2196	47.20	1.0e-4
4	Inertia Weld, HT 1375°C, 12hr, Air	900	2	390	47.71	2.0e-4
5	Inertia Weld, HT 1375°C, 12hr, Air	950	2	102.6	48.47	4.0e-4
6	Inertia Weld, HT 1375°C, 12hr, Air	975	2	19	47.81	9.0e-4
7	Inertia Weld, HT 1375°C, 12hr, Air	975	2	25	48.08	4.6e-4
8	Inertia Weld, HT 1375°C, 12hr, Air	925	2	478	48.92	2.4e-4
9	Inertia Weld, HT 1375°C, 12hr, Air	900	2	1021	48.59	1.4e-4

Status: Inertia Welded Joint Performance

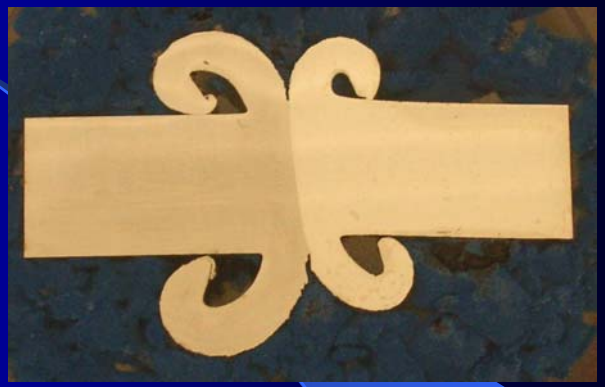


Iterative Process Development yielded micro-structural modifications with enhanced & reproducible high temperature creep performance.

HTHE Prototype: Tube–Header Dissimilar Joint



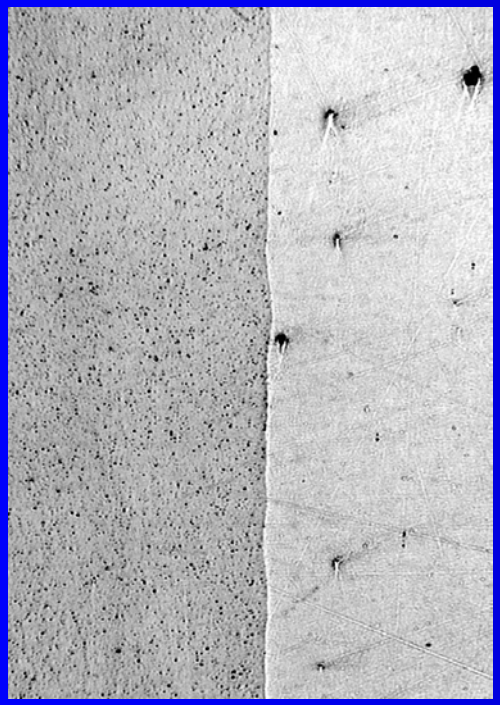
MA956 IN601



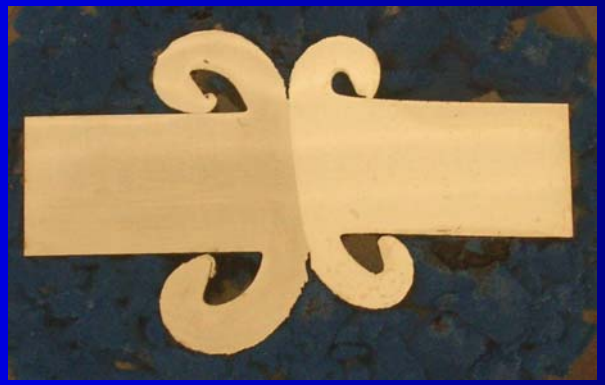
Candidate Materials	Solution Anneal, Recrystallization Temperature, °C	Alloy Melting Temperature, °C	Proposed HT Temperature, °C	Required Post Anneal Treatment
MA956	1375	1480	1375	NA
IN601	1000-1080	1360-1411	1100	Fast Cool
IN617	1193	1332-1377	1200	Fast Cool
Haynes230	1177 -1246	1290-1375	1250	Fast Cool
IN740	1150-1200	1293-1369	1200	Age@750-800

Dissimilar IN601, IN617- MA956 Joining

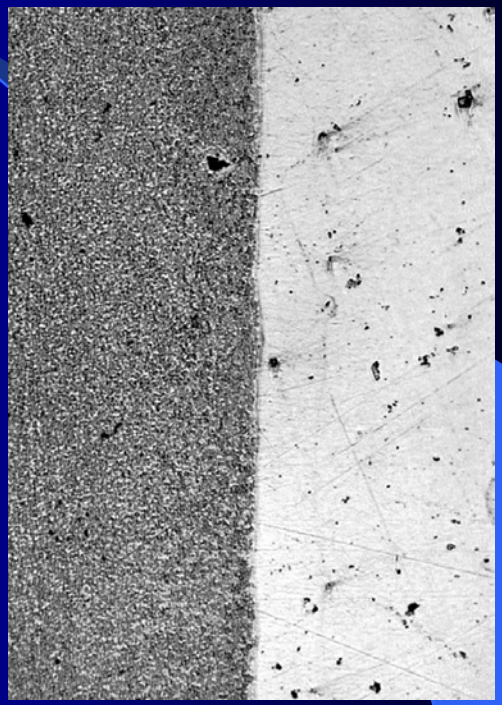
As-polished view



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.

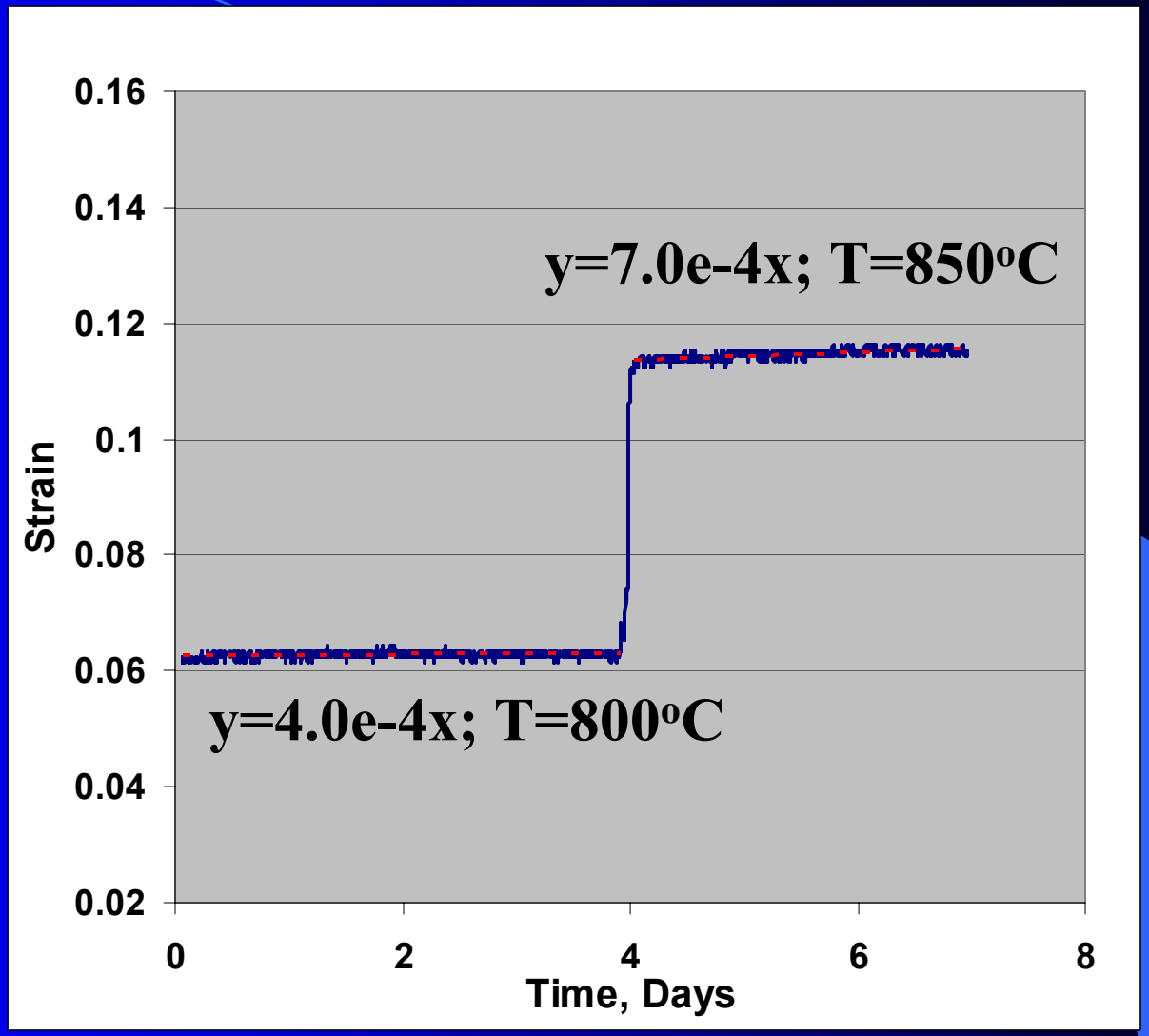
IN601-MA956 Incremental Creep Test

HT:
1300°C–1hr

Test Condition
2ksi Stress
Test in Air

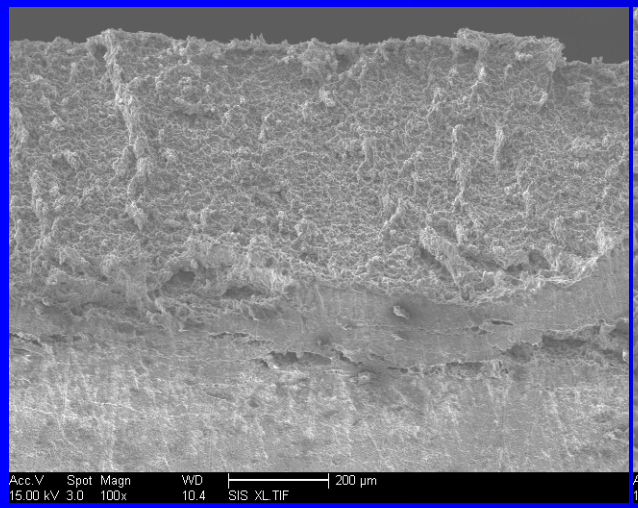
Results
High Creep Rate Observed

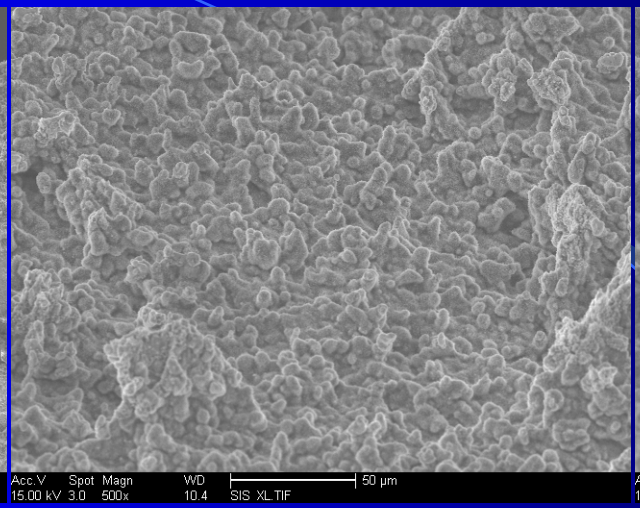
Failure
IN601 Side

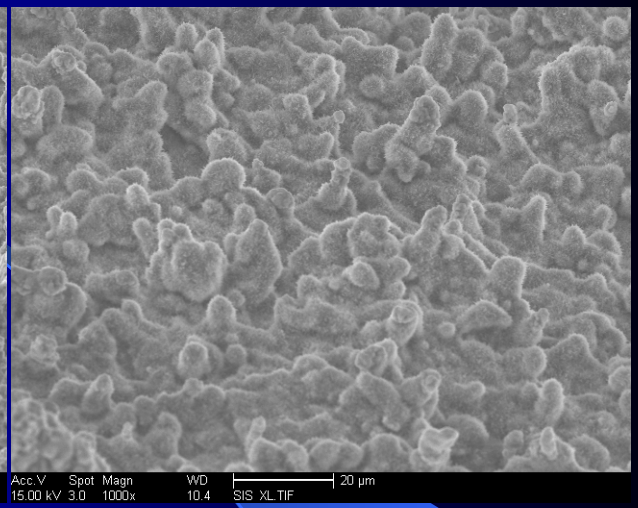


creep strength limited by the weakest link

IN601-MA956 Joint: Fracture Evidence







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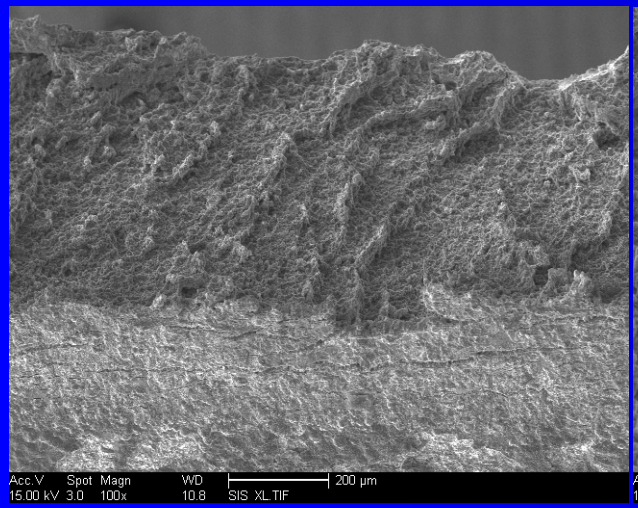

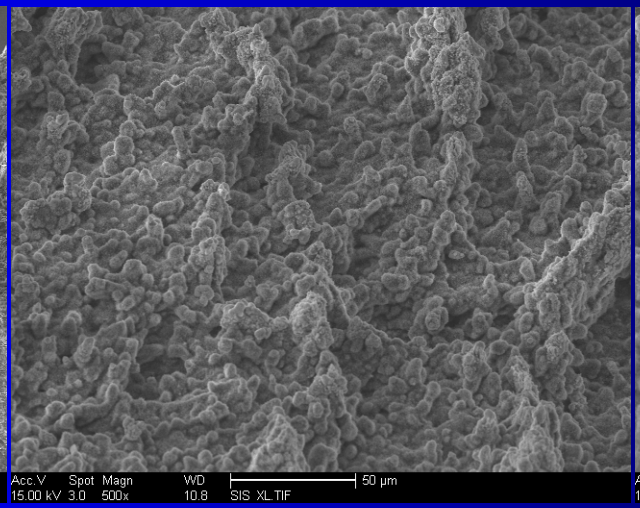

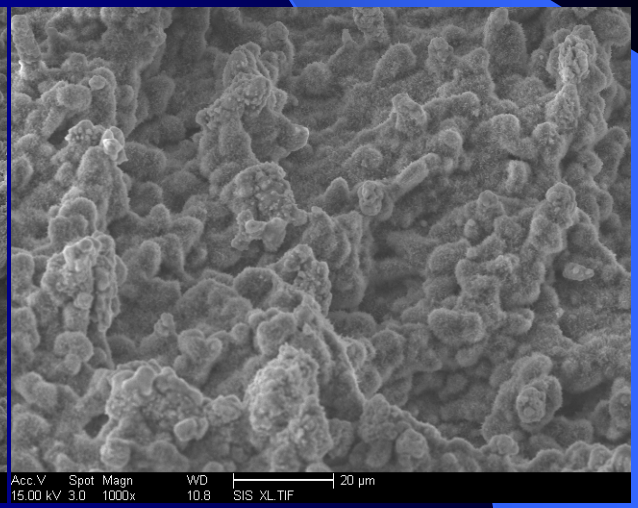

Fracture similar to poor performing MA956 joint

Summary of Results

- Robust inertia welding joining methods are 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
- Acceptable joining protocols being developed for solution strengthened Ni-base, Ni-Cr alloys
- Precipitate strengthened IN740 joints pending
  issue with initial microstructure & PWHT