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Title: Welding Metallurgy and Processing Issues for Joining of Power Sources

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Welding Metallurgy and Processing Issues for Joining of Power Sources

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Reviewed for Classification by M. Paffett
Per Classification Guide CG-LANL-COMP-1, 8/09, DOE-OC

Outline

Metallurgy

- Alloy 25
  - Physical Metallurgy of Alloy 25.
  - Weldability Issues with Alloy 25.
  - Metallography of GTA Weld on Alloy 25.
- Ta-10W
  - Physical Metallurgy of Ta-10W.
  - Weldability Issues with Ta-10W.
- 21-6-9 (Nitronic 40)
  - Physical Metallurgy of 21-6-9.
  - Weldability Issues with 21-6-9.

Processing

- Welding with Fiber Laser & Pulsed Nd:Yag Laser
- Laser Beam Profiling
- EB Experience and Profiling (not specifically discussed here)

What we are doing with Alloy 25

Physical Metallurgy of Haynes 25

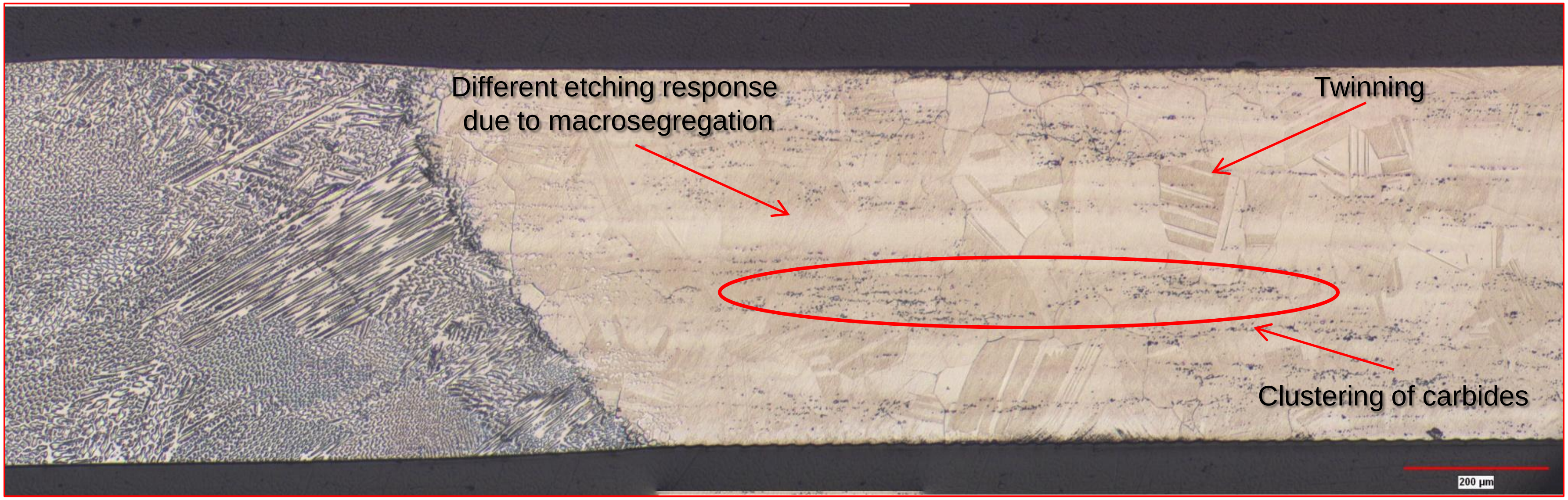
- **Haynes 25 (aka L-605) is a solid-solution strengthened alloy based on the Co-Cr-W-Ni-C with excellent high-temperature strength and oxidation resistance to ~1100°C.**
- **The microstructure of the Haynes 25 alloy is characterized by equiaxed grains with an FCC crystal structure. The grains typically contain many twins and stacking faults owing to a low SFE. Cold work increases the SF density**
- **W-rich M_6C-type carbides several microns in size are distributed throughout the grain interiors and along grain boundaries. Cr-rich $M_{23}C_6$-type carbides can also be precipitated on stacking faults between 650°C to 1050°C causing an increase in strength.**
- **The Laves phase Co_2W can also form at a slightly higher temperature range resulting in embrittlement.**

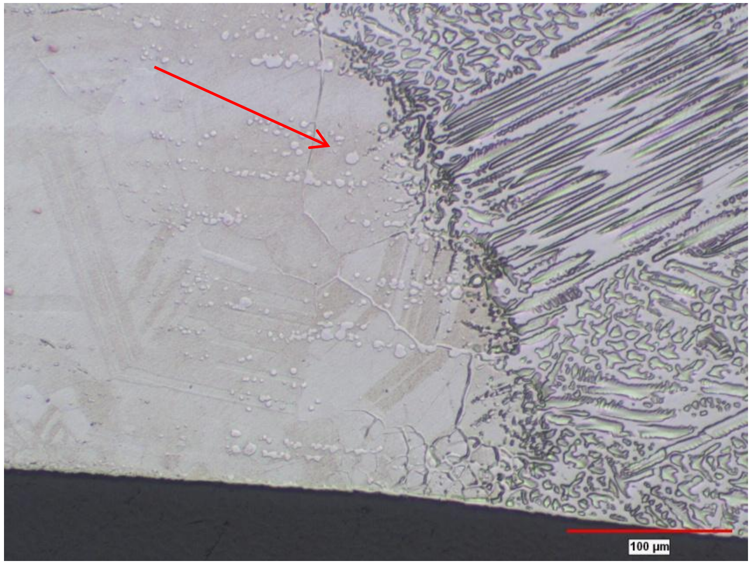
Weldability Issues - Alloy 25

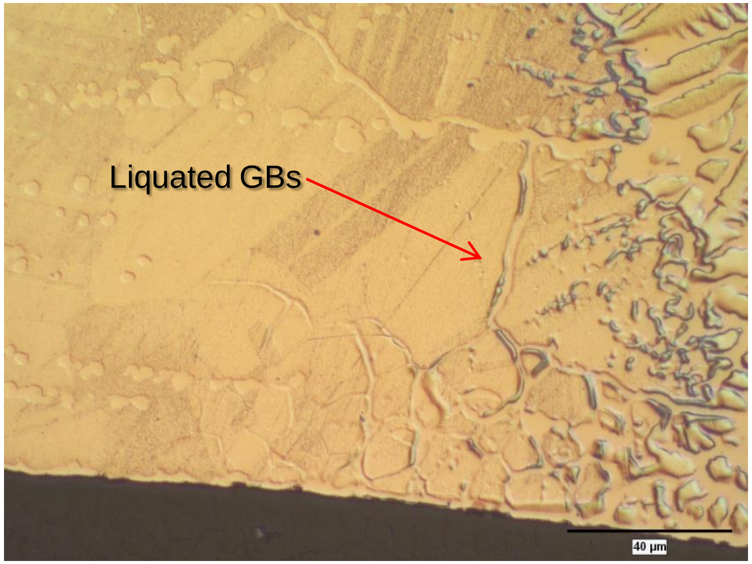
- Propensity for cracking in the HAZ due to liquid formation around carbides (see micrographs) by a process called Constitutional Liquation*. Considerable evidence of HAZ liquation was observed in micrographs of GTA weld but no cracking was found.
- An immersion etch of H_2O-HCl-H_2O_2 works best for revealing features of weld and base metal.
- Propensity for formation of Laves phase in fusion zone and HAZ during high temperature thermal cycles (such as in HAZ during welding) and subsequent embrittlement in service.

* Pepe & Savage, *Welding Journal*, 1967.

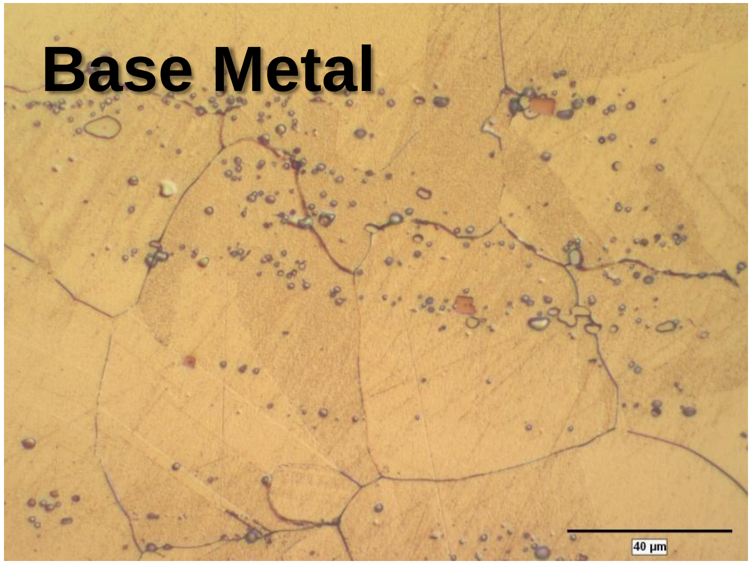
Metallography of GTA Weld

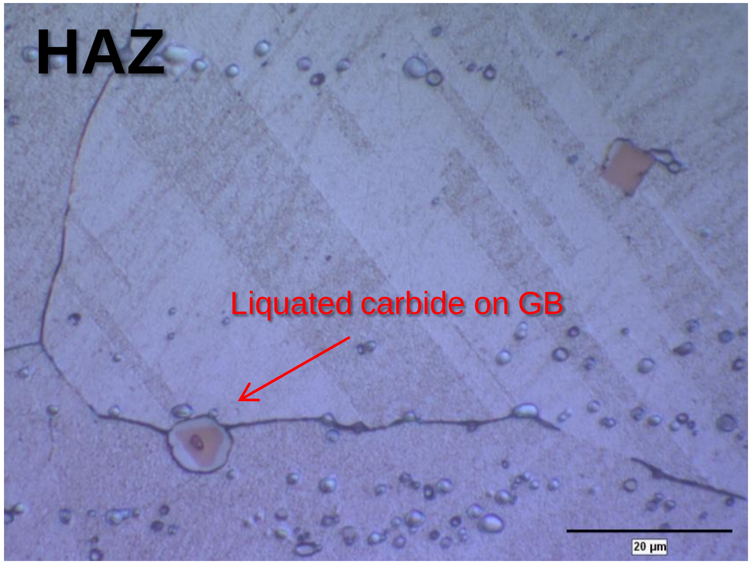


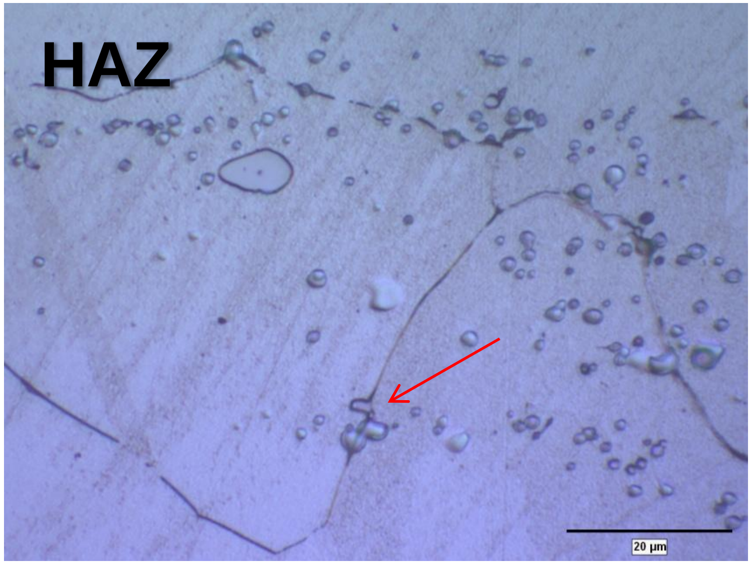




Metallography of GTA Weld







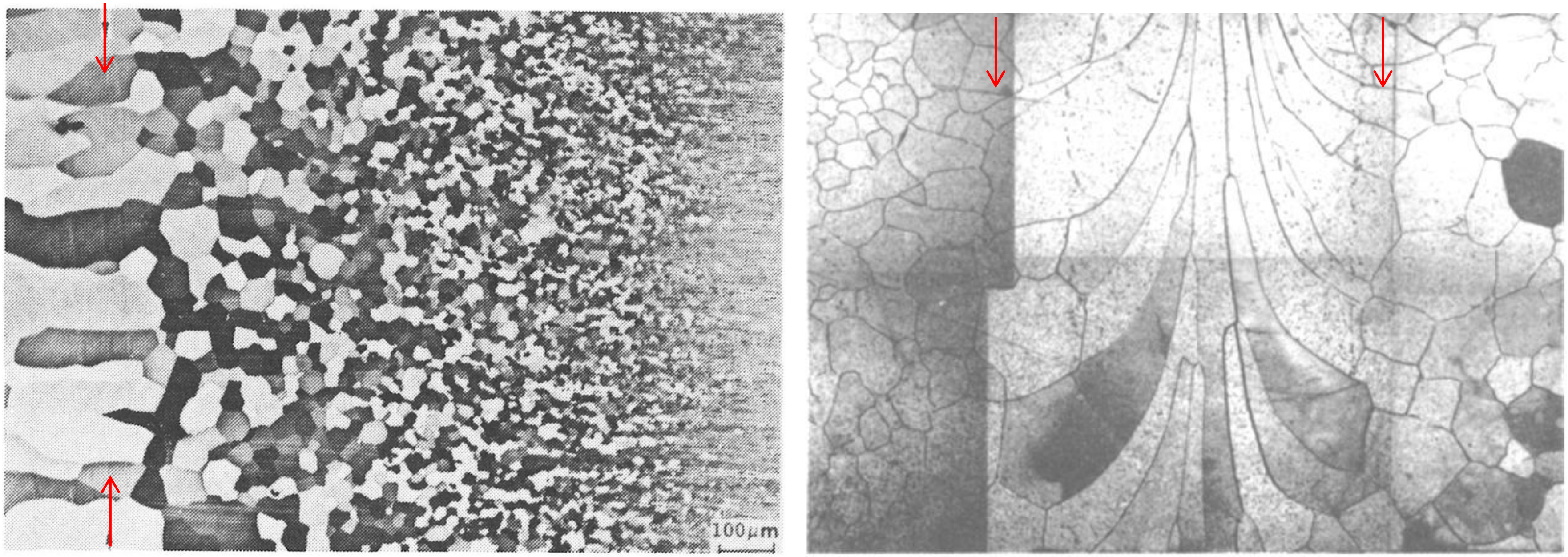
Physical Metallurgy of Ta-10W

- Ta-10W (ASTM B365) is a single-phase, solid-solution strengthened alloy with a BCC crystal structure that is based on the isomorphous Ta-W system.
- It cannot be strengthened via heat-treatment or aging.
- It is sensitive to interstitial content (C,H,O,N are specified at very low levels, <0.010%) that raises the DBTT, although it is less sensitive than its refractory counterparts.
- It has good ductility, high modulus, excellent corrosion resistance and can be used at high temperatures.

Weldability Issues - Ta-10W

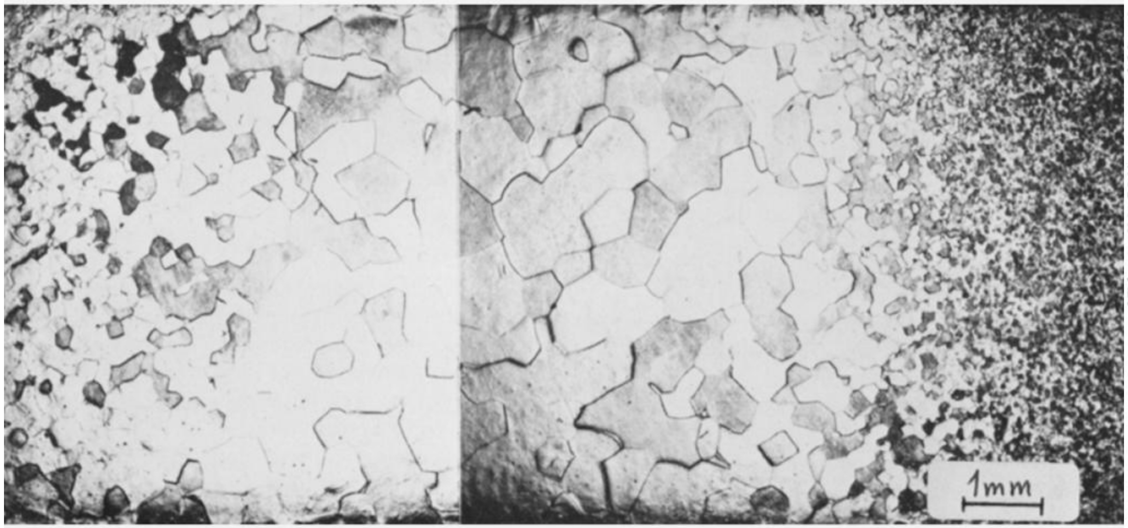
- Owing to the sensitivity to interstitial content, welding must be accomplished using high vacuum EBW or GTAW in a high purity glovebox.
- Because Ta-10W is single phase from room temperature to the solidus where melting begins, considerable grain growth occurs in the HAZ (no 2nd phase to pin GBs).
- Development of undesirable crystallographic textures is possible in weld region due to epitaxial growth from large grains and competitive growth during solidification in direction of local maximum thermal gradient.
- Long columnar grains in the fusion zone may be elim-inated with pulsing and/or arc oscillation (with GTA).

HAZ Grain Growth & Columnar Grains

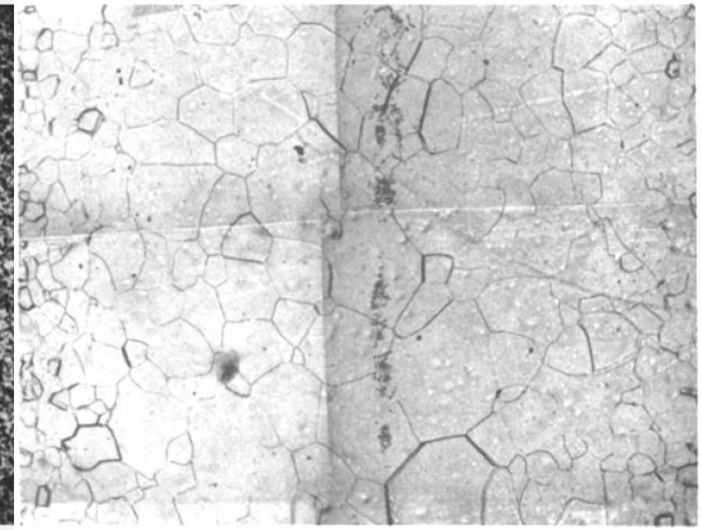


- **Examples of grain growth in GTA welds on Ta alloys (from papers by Grill and coworkers).**
- **Arrows indicate approximate position of the fusion boundary.**

Effects of Pulsing & Oscillation



Effects of Pulsing



Effects of Oscillation

- **Grill and coworkers have shown that pulsing and /or arc oscillation with GTA can limit the extent of columnar growth in Ta alloys.**
- **Pulsing and/or beam oscillation with the Pro-Beam LVEBW is recommended.**

Physical Metallurgy of 21-6-9

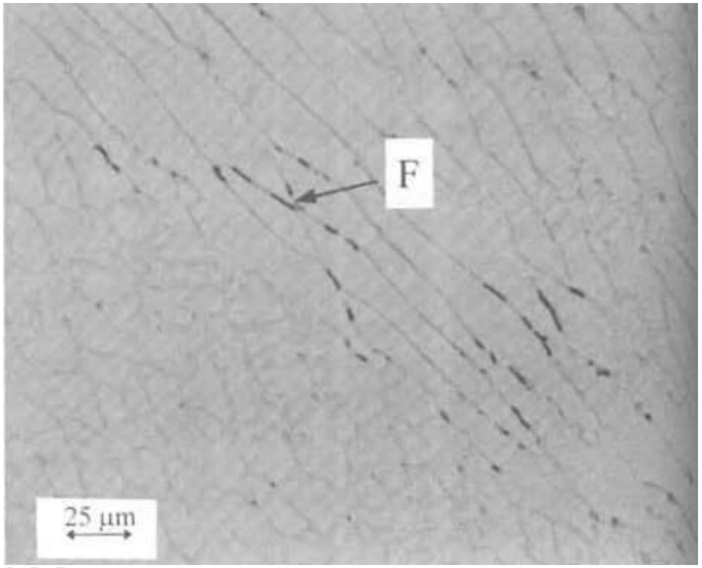
- Alloy 21Cr-6Ni-9Mn (21-6-9) is a high Mn, nitrogen-strengthened, austenitic stainless steel based on the Fe-Mn-Cr-Ni-N-C system with a nominal composition of 21Cr-6Ni-9Mn-0.3N (all wt%). It is also known commercially as Nitronic 40and UNS21900 (or UNS21904 depending on the C content).
- N is a potent interstitial solid-solution strengthener. As a result, 21-6-9 has significantly higher strength than typical 300-series stainless steels in the annealed condition.
- N additions also increase the austenite stability, so the austenitic structure of 21-6-9 is very stable and remains fully austenitic (and thus non-magnetic) even after extensive deformation at room temperature.

Weldability Issues - Nitronic 40

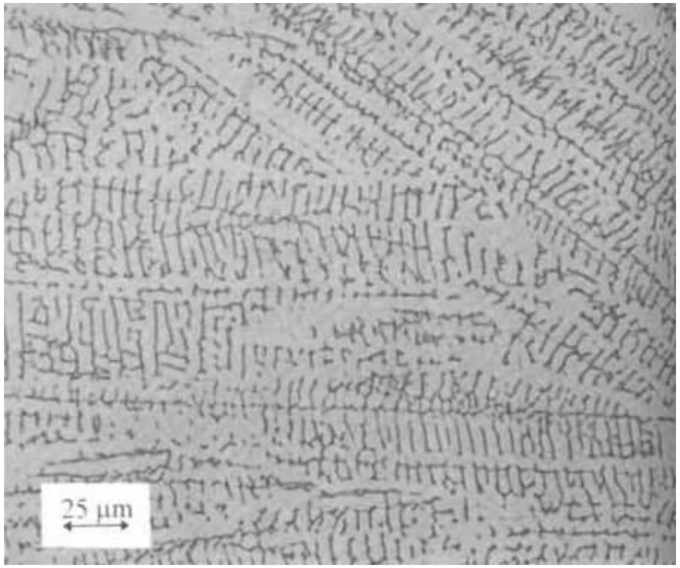
- Certain issues are similar to those for 300 series stainless steels: solidification cracking of heats with improper Creq/Nieq ratio occurs, especially during LBW. See: (1) T.J. Lienert and J.C. Lippold, "An Improved Weldability Diagram for Laser-Welded Austenitic Stainless Steels," *Science & Technology of Welding & Joining*, Vol. 8(1), pp. 1-9, 2003 and (2) T.J. Lienert and K.J. Hollis, "Method For Pre-placing Of Filler Metals For Micro-welding Of Alloys Susceptible To Solidification Cracking", U.S. Patent Application 13358295, filed January 25, 2012.).
- Issues related to evaporation of Mn & N during LBW are also a possible concern to loss of strength. This issue can be overcome by defocusing of the laser or electron beam. See: "Review of Processing of Type 21Cr-6Ni-9Mn Stainless Steel", Lienert et. al, LA-UR-08-3312.

Weldability Issues – 21-6-9

- **Effects of rapid thermal cycles on the primary solidification mode and cracking: the composition of 21-6-9 is balanced to achieve primary solidification to the ferrite phase (FA mode). EB and LB welds in some WR heats exhibit both AF and FA modes of solidification stemming from the rapid thermal cycle. AF mode is prone to solidification cracking.**
- **Suggest procurement of a heat with proper Creq/Nieq.**

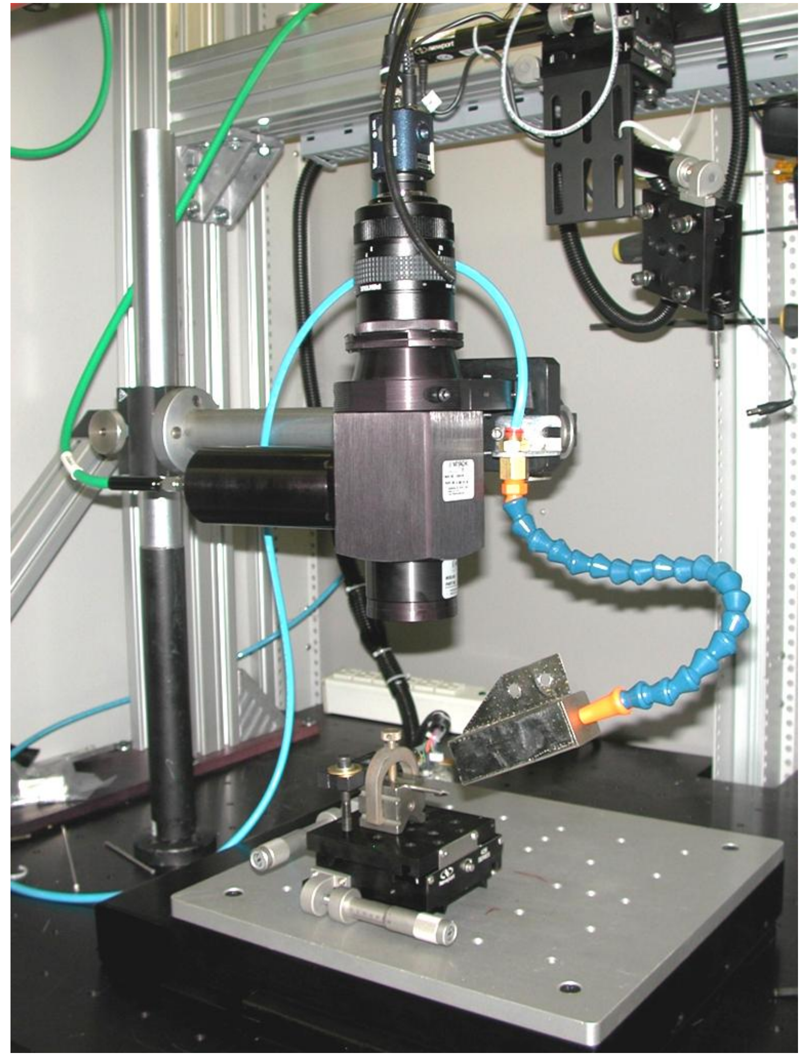


AF Solidification Mode



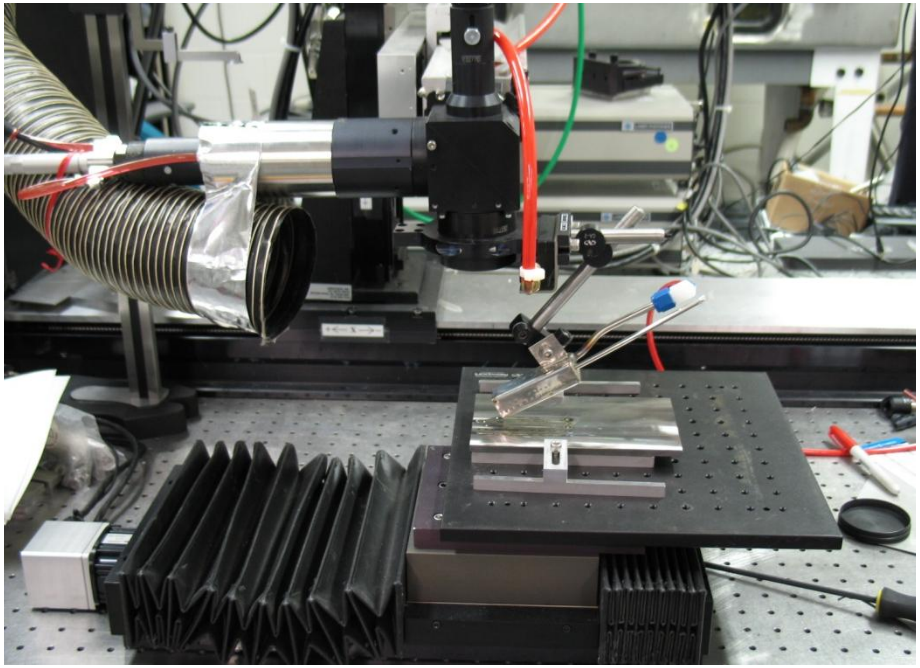
FA Solidification Mode

Laser Beam Welding at MST-6



Unitek-Miyachi 70 W Pulsed Nd:YAG Laser

Laser Beam Welding at MST-6



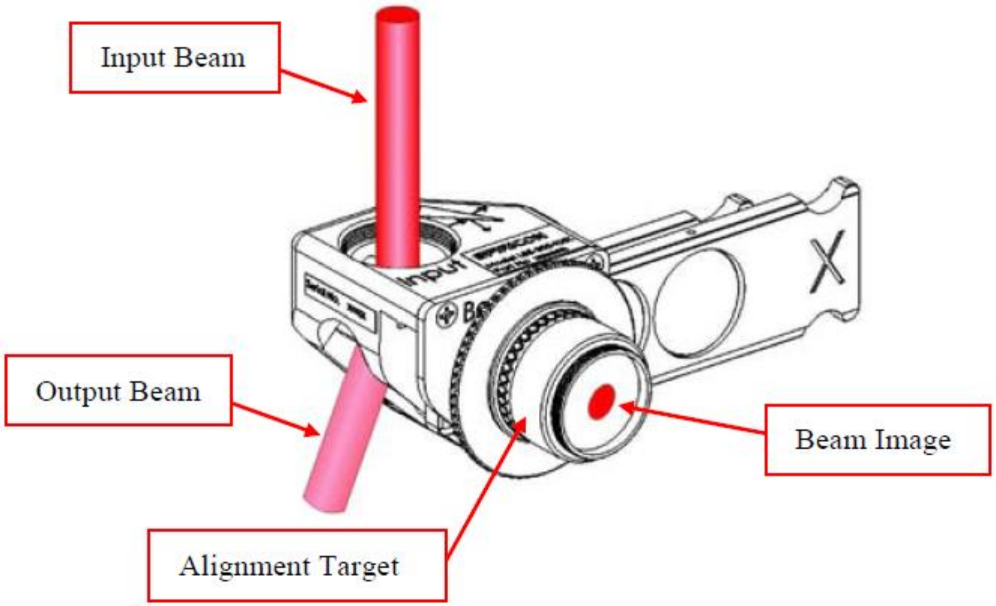
IPG 6 kW Yb-Fiber Laser

- **Even for those with laser experience, this laser requires care in operation. It is very sensitive to dust on optics and is prone to back-reflections that can damage modules.**
- **Recommend welding off top-dead-center with round parts to avoid back-reflection into fiber optic.**

Laser Beam Profiling

- Characterization of laser performance by beam profiling is mandatory for assuring ***repeatable results in production activities***. It is also needed to ***establish equivalence between laser systems to allow transfer of parameters*** between the two systems, and provides ***fundamental insights*** for process development.
- MST-6 has considerable experience in beam profiling of CW and pulsed laser systems:
  - Power and beam profiling of IPG fiber laser welder using PRIMES Power Meter and Focus Monitor.
  - Beam profiling of Nd:YAG laser welder using Ophir-Spiricon LBS-500 profiler and Kapton film.

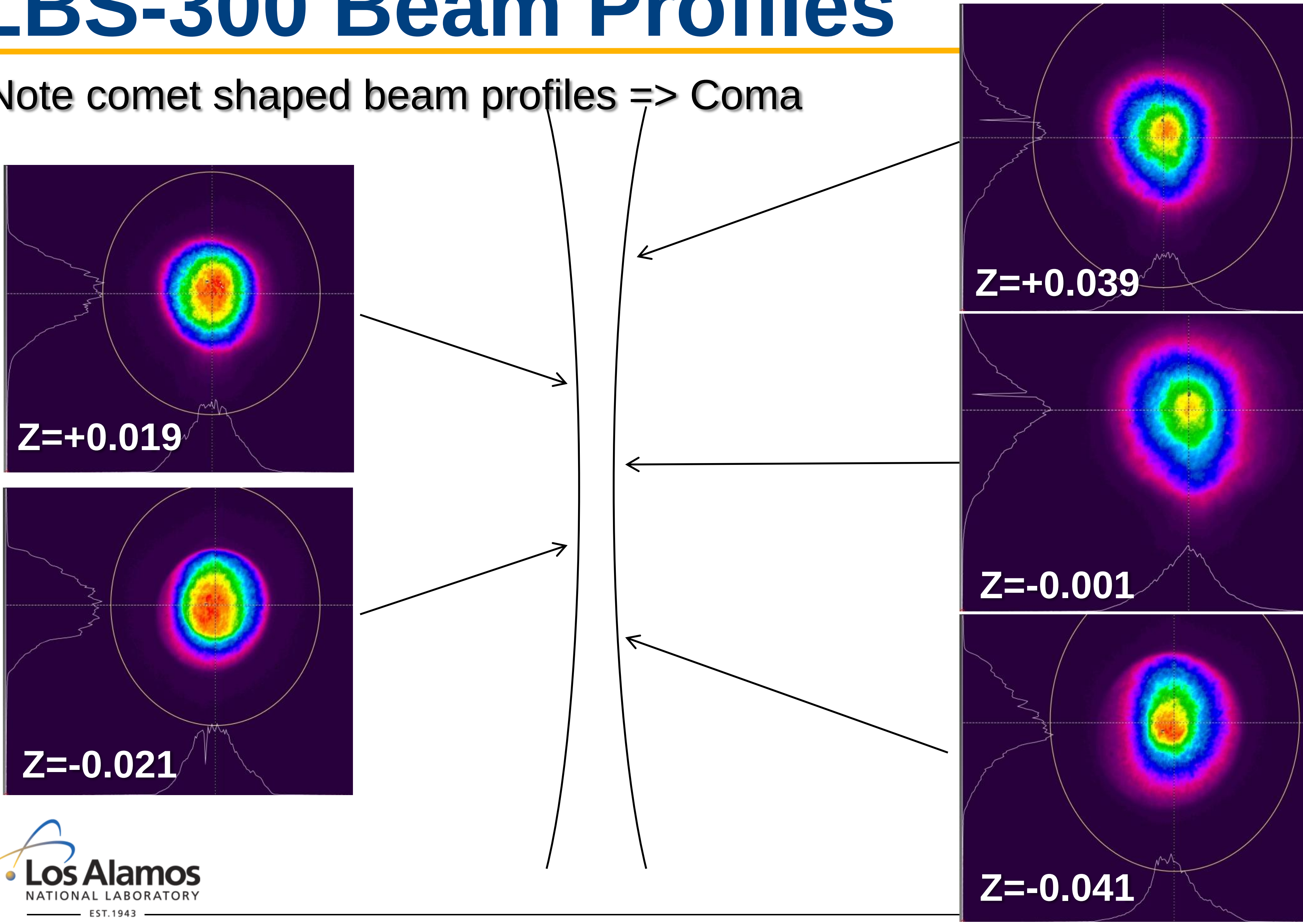
Ophir-Spiricon LBS-300 System



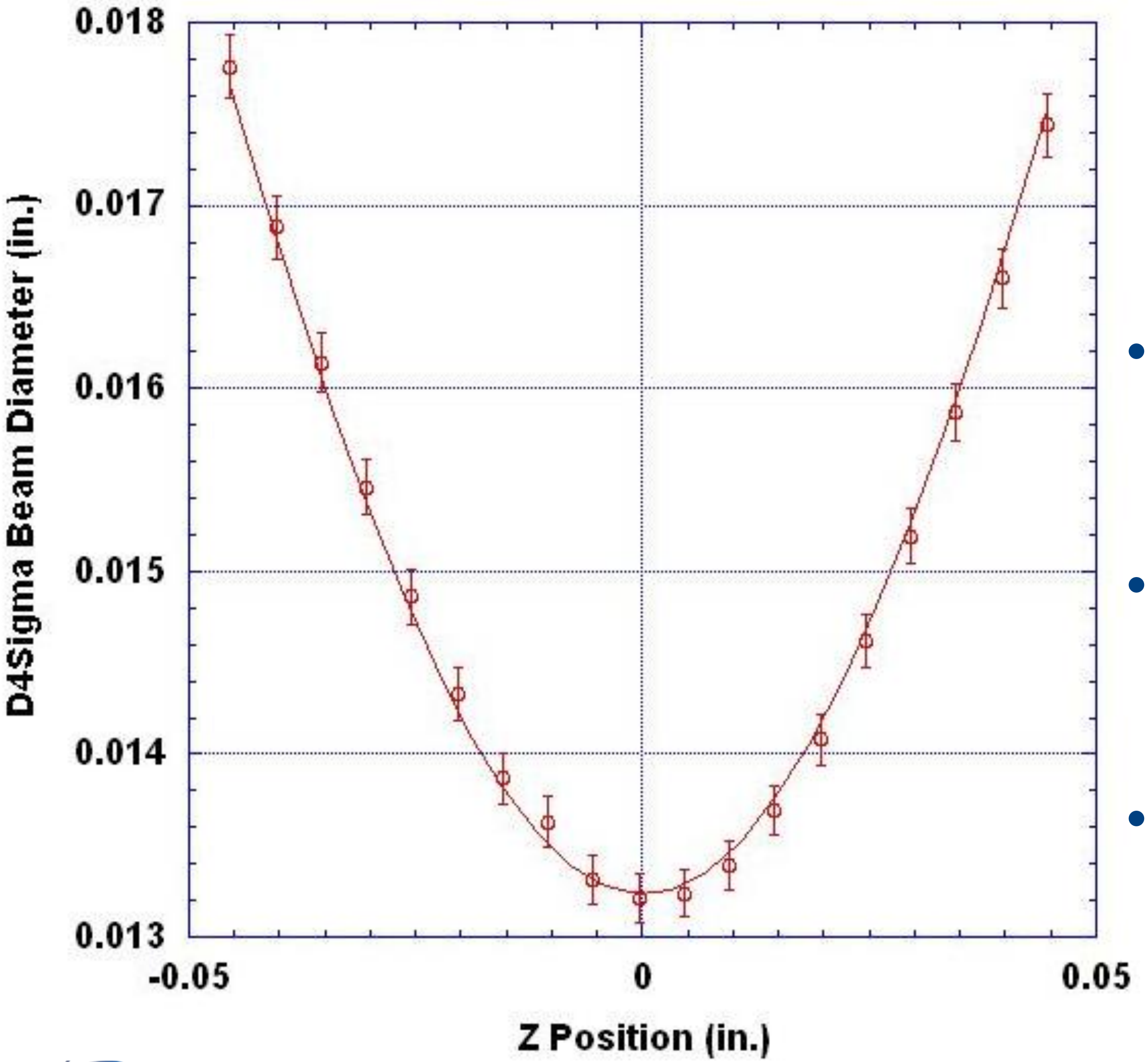
- **This system is used for profiling of pulsed lasers.**
- ***The optical axis of the system must be closely aligned to the beam axis for useful results.***

LBS-300 Beam Profiles

Note comet shaped beam profiles => Coma



LBS-300 Profiler Data



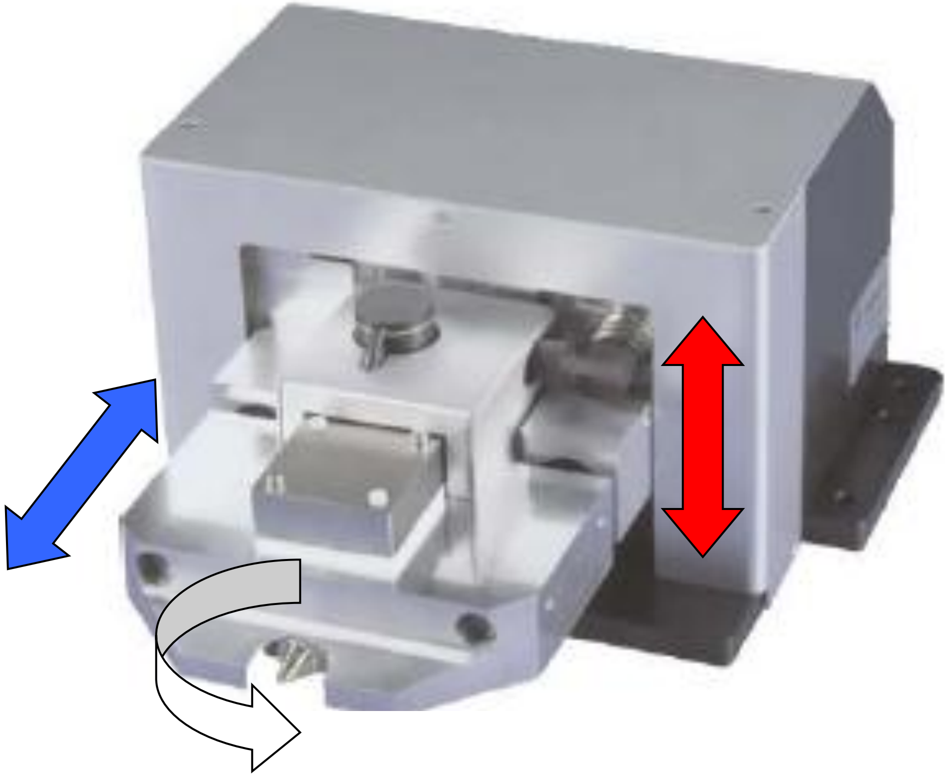
y = m1*sqrt(1+(m0*m2*.001064...		
	Value	Error
m1	0.013232	2.9922e-5
m2	10.063	0.053893
Chisq	1.1617e-7	NA
R^2	0.99709	NA

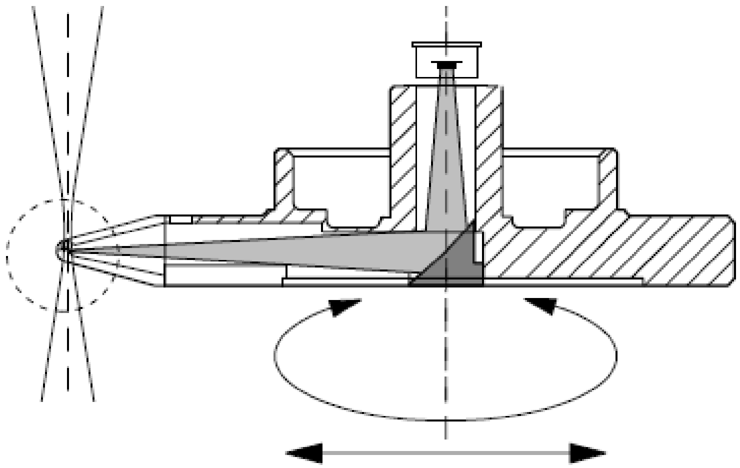
- Fitting assumes that the caustic is sym-metric about z=0.
- The fitting parameters indicate that $2w_0 \approx$ 0.0132” and $M^2 \approx 10.0$.
- Note the very good but slightly assy-metric fit => Coma due to misalignment?

PRIMES Focus Monitor

- Allows measurement of a number of important beam parameters including: spatial profile of the focused beam, the position of the minimum beam diameter of the focused beam, the Rayleigh length and the beam propagation ratio (M^2).
- Allows detection of alignment errors and changes in the laser system that may affect laser operation and can aid in determining optimal processing parameters to maximize performance.
- You will see a demonstration of this equipment in the MST-6 laser lab if time permits.

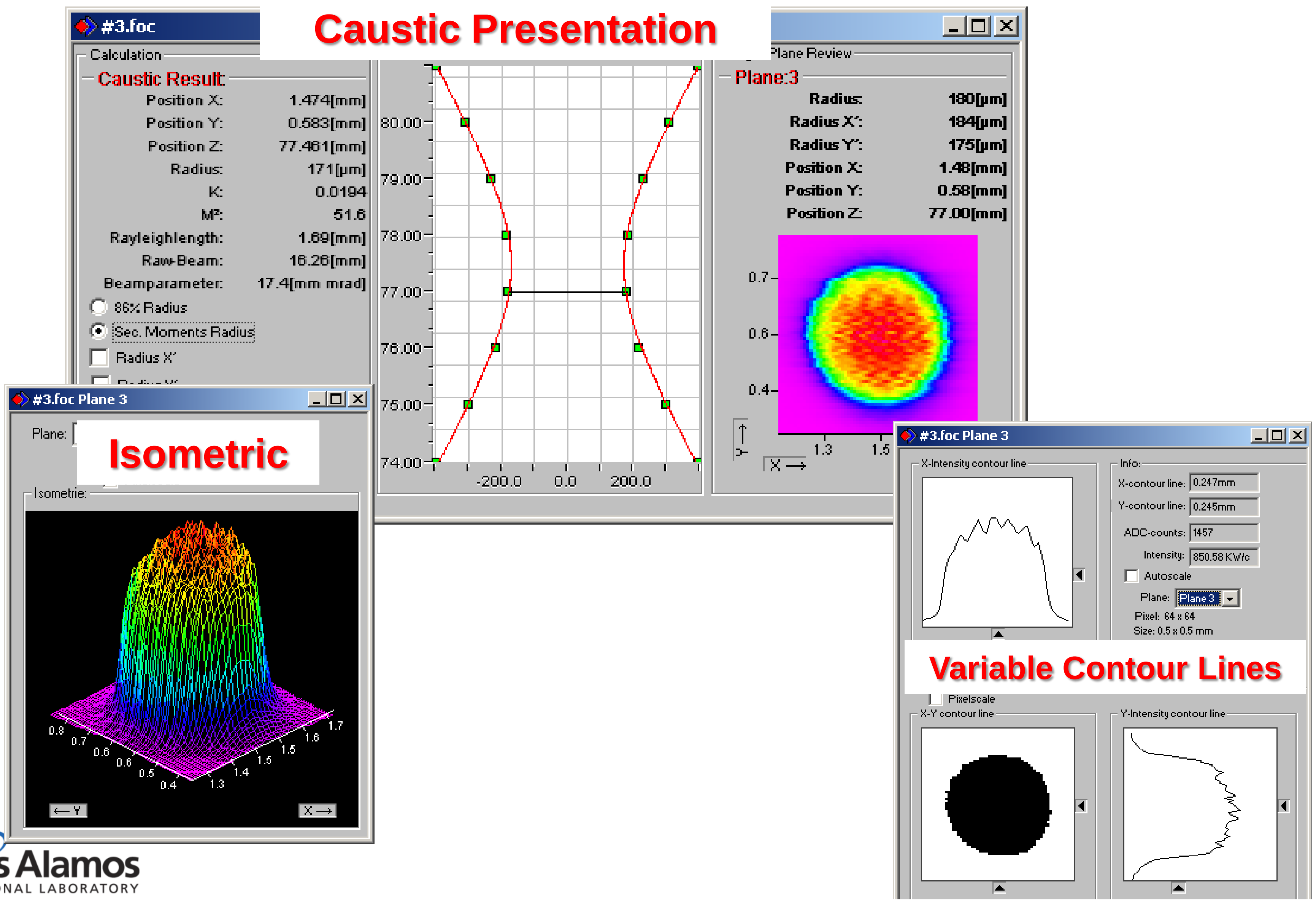
PRIMES Focus Monitor





Beam path within the Focus Monitor.

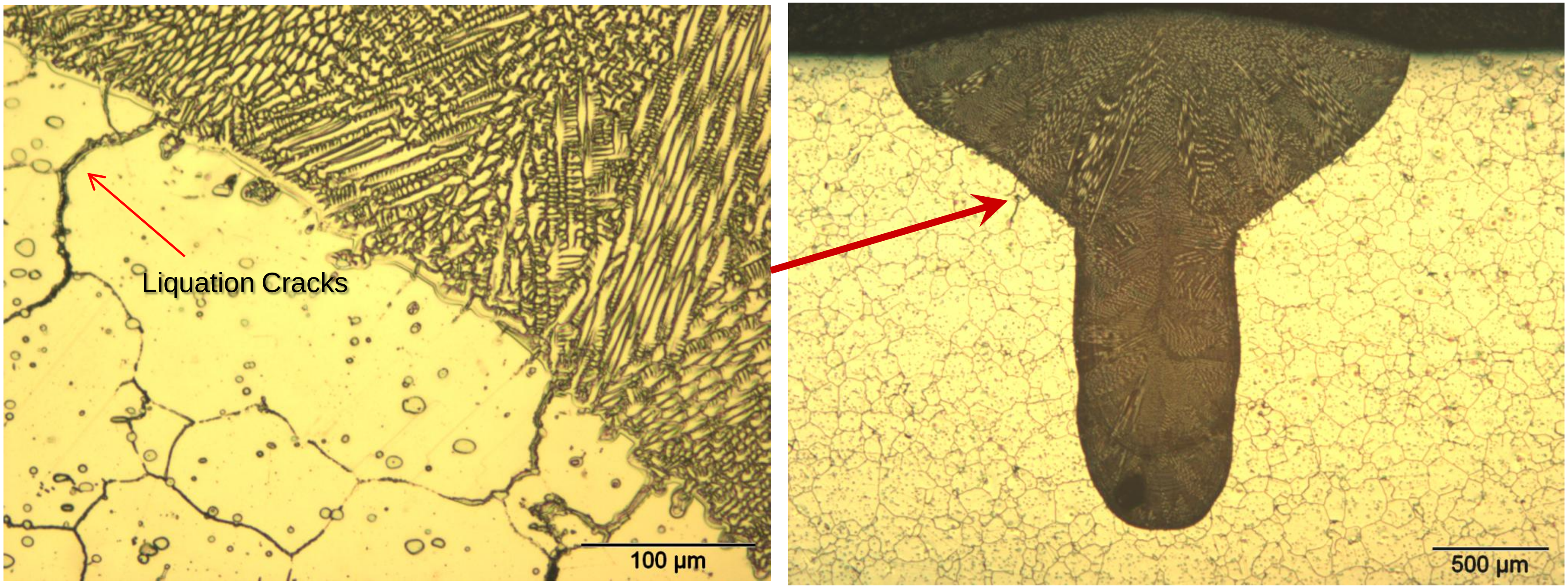
Presentation Options



What We are Doing with Alloy 25.

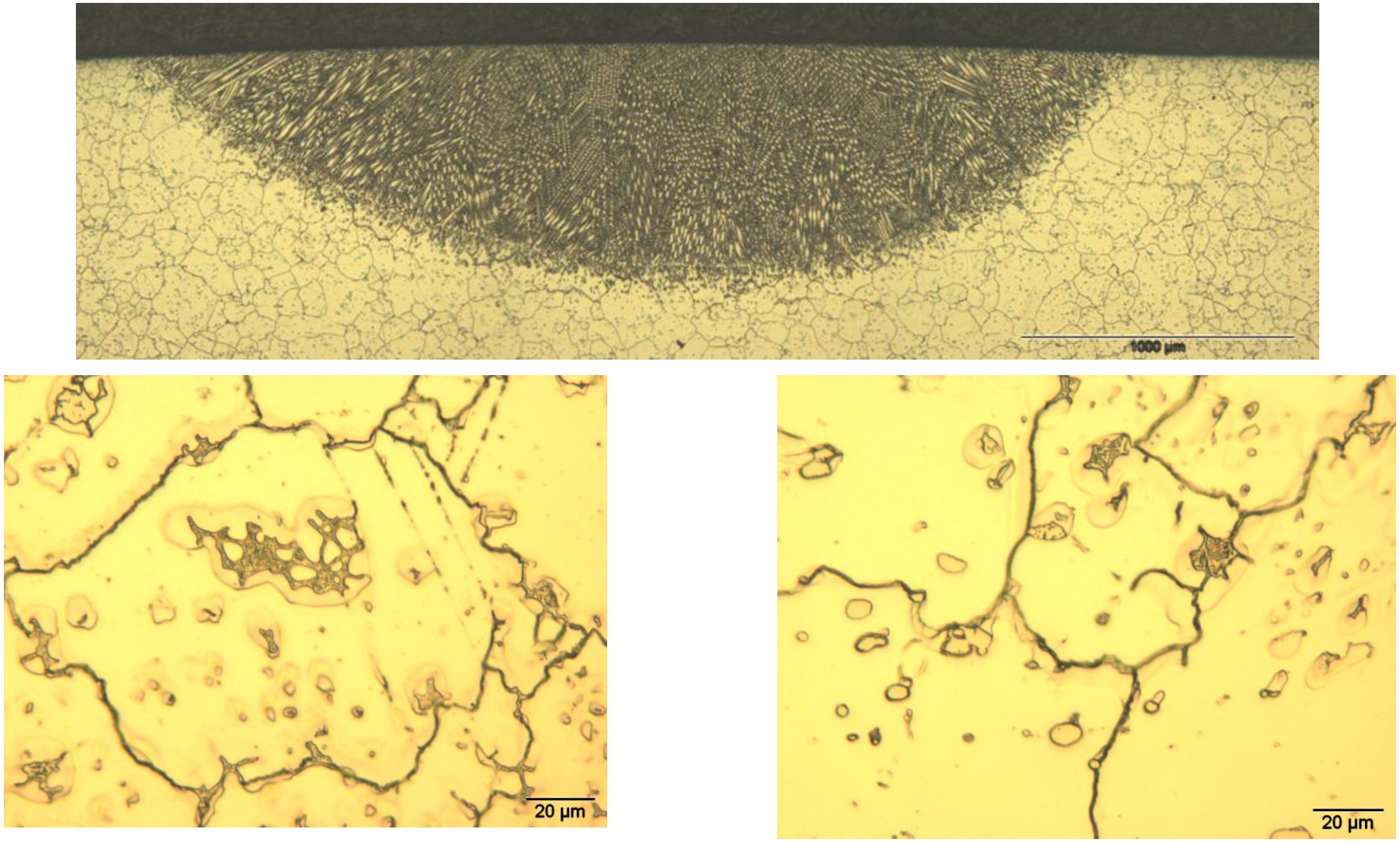
- **Arranged with contacts at Haynes International to acquire several sq. ft. of 0.0125" sheet of Alloy 25.**
- **A set of EB welds have been produced on this heat of Alloy 25. EB welds were made in both defocused and sharply focused conditions. Specimens (tensile, bend & metallographic) are being EDM cut from the weld and are due back from the shop this week. *Results are imminent.***
- **Hot-ductility tests using the Gleeble thermo-mechanical simulator are planned to assess the propensity for liquation cracking. A thermal cycle that is representative of GTAW has been developed using a Rosenthal approach. Gleeble specimens are due back from the shop in 2 weeks. Renewal of IWD and maintenance of Gleeble machine are complete. *Results are expected in a few weeks.***
- **We will follow the same process for Alloy 25 as for our previous work on Haynes 230 outlined in the next several slides.**

LBW of Haynes 230



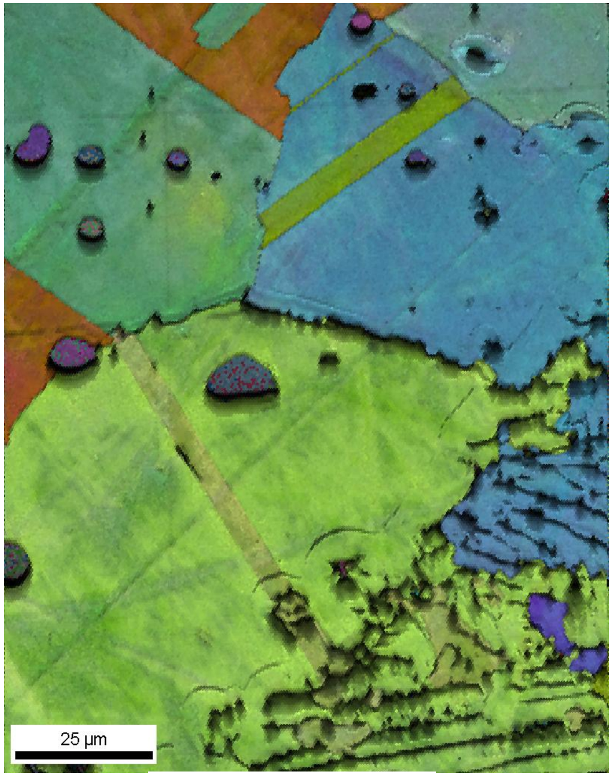
- **Haynes 230 is the Ni base analog of Haynes 25. It is very similar from physical and welding metallurgy standpoint to Haynes 25.**

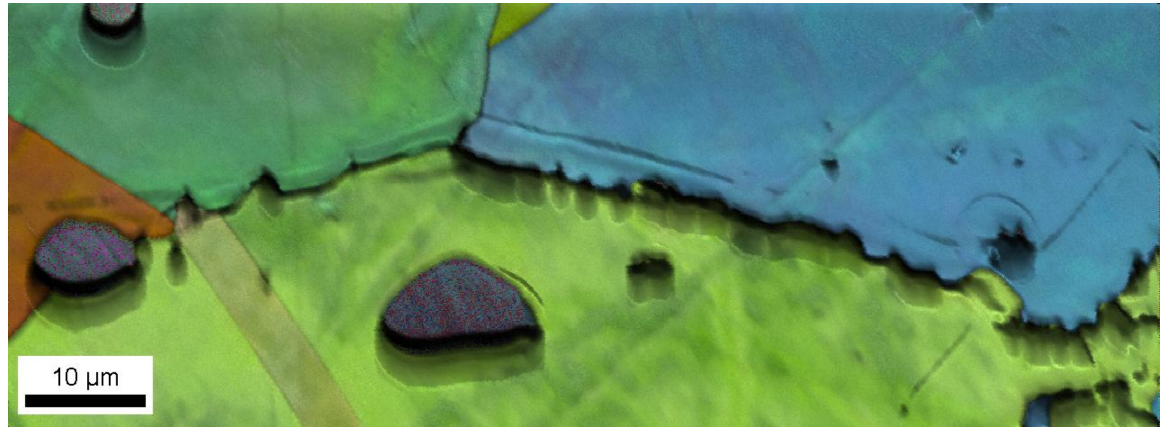
LBW of Haynes 230

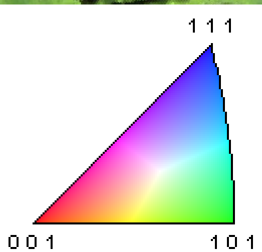


- **Based on the similarity between the two alloys, EB welds were produced on Alloy 25 in both defocused and sharply focused conditions.**

OIM/EBSD Data - LBWs

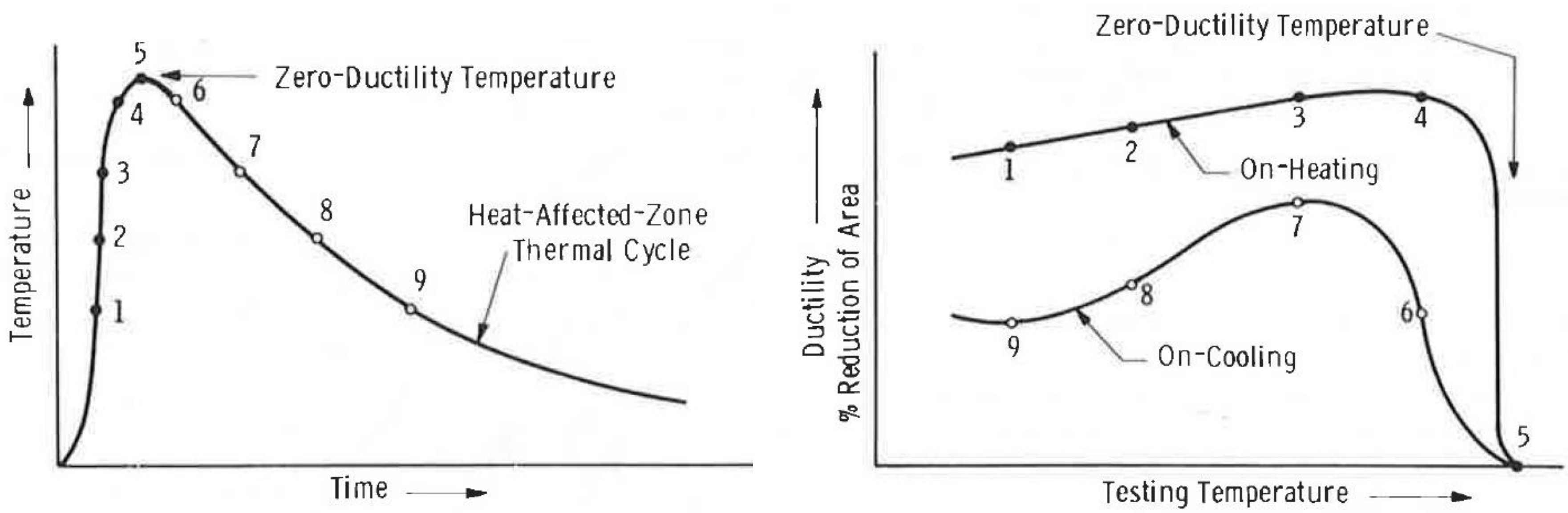






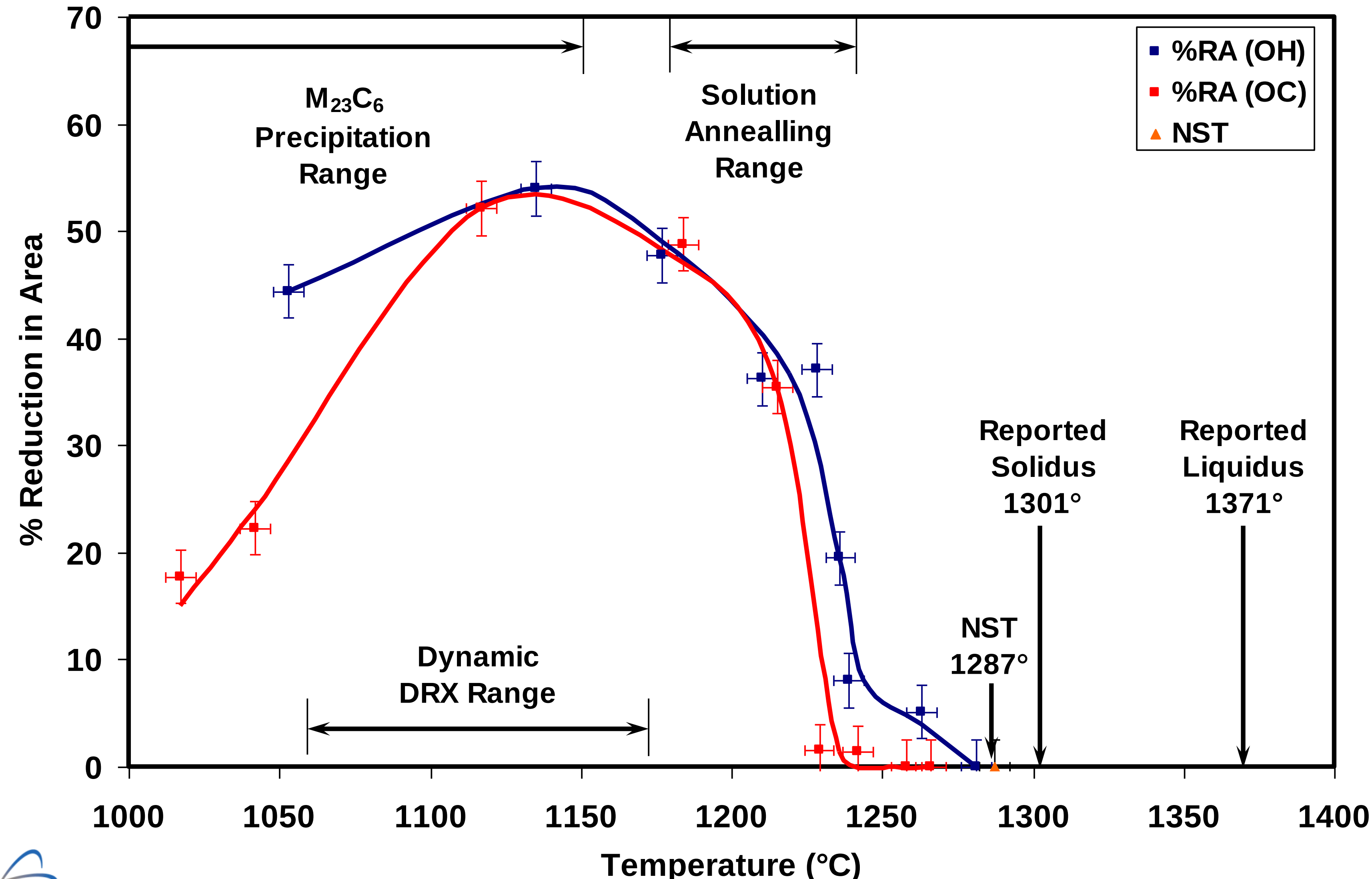
- **Back-filled boundary is a random high angle boundary (~31° misorientation).**
- **Note that low angle boundaries and twin boundaries along fusion boundary did not back-fill.**

Hot Ductility Testing



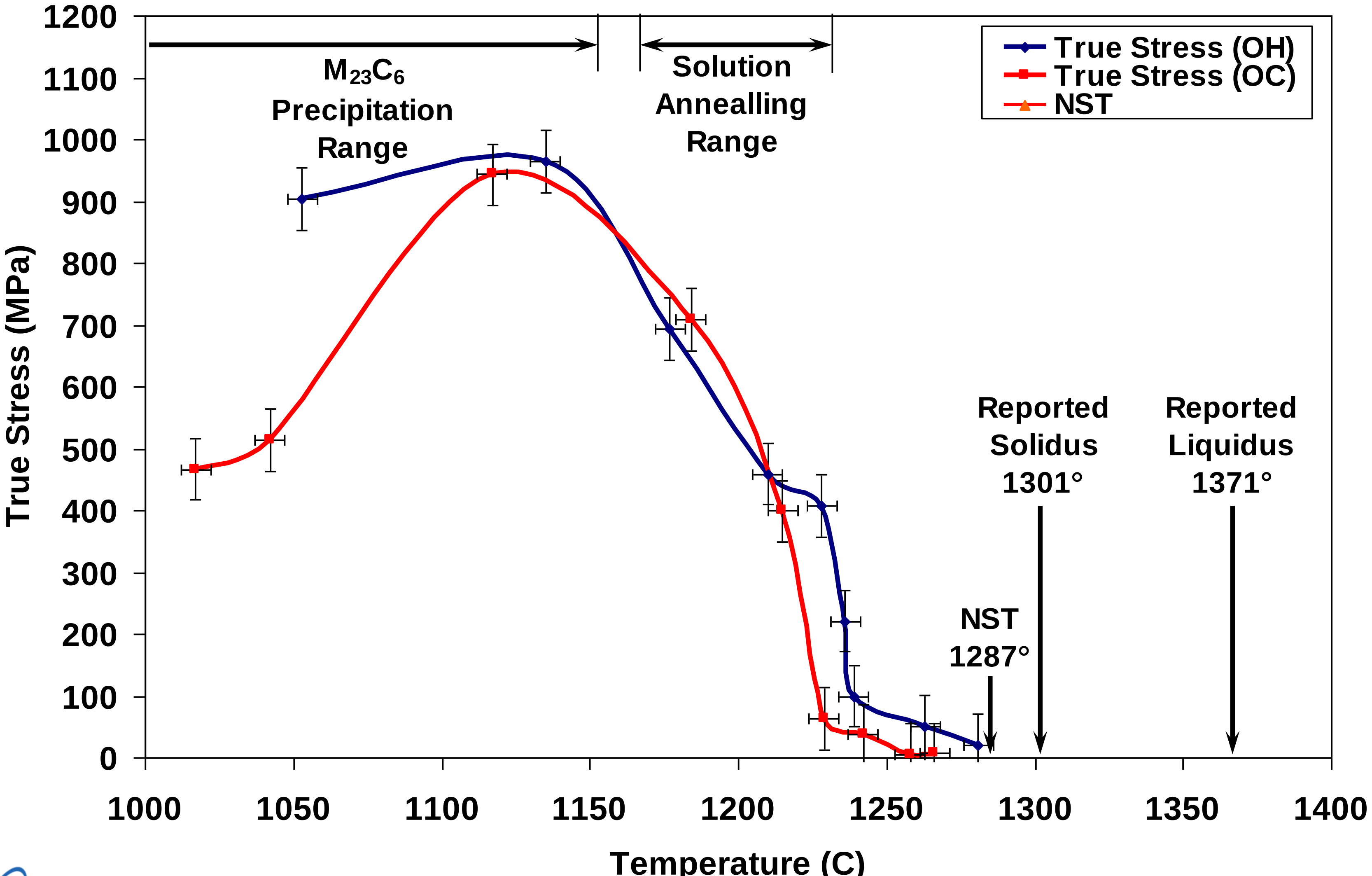
- **Used to assess the propensity for liquation cracking near the solidus temperature and mechanical behavior at lower temperatures. The sample is resistively heated and follows a simulated HAZ thermal cycle. Samples are pulled to failure at different positions along the thermal cycle.**
- **Ductility and tensile strength are plotted OH & OC.**

Hot Ductility Data Alloy 230-%RA



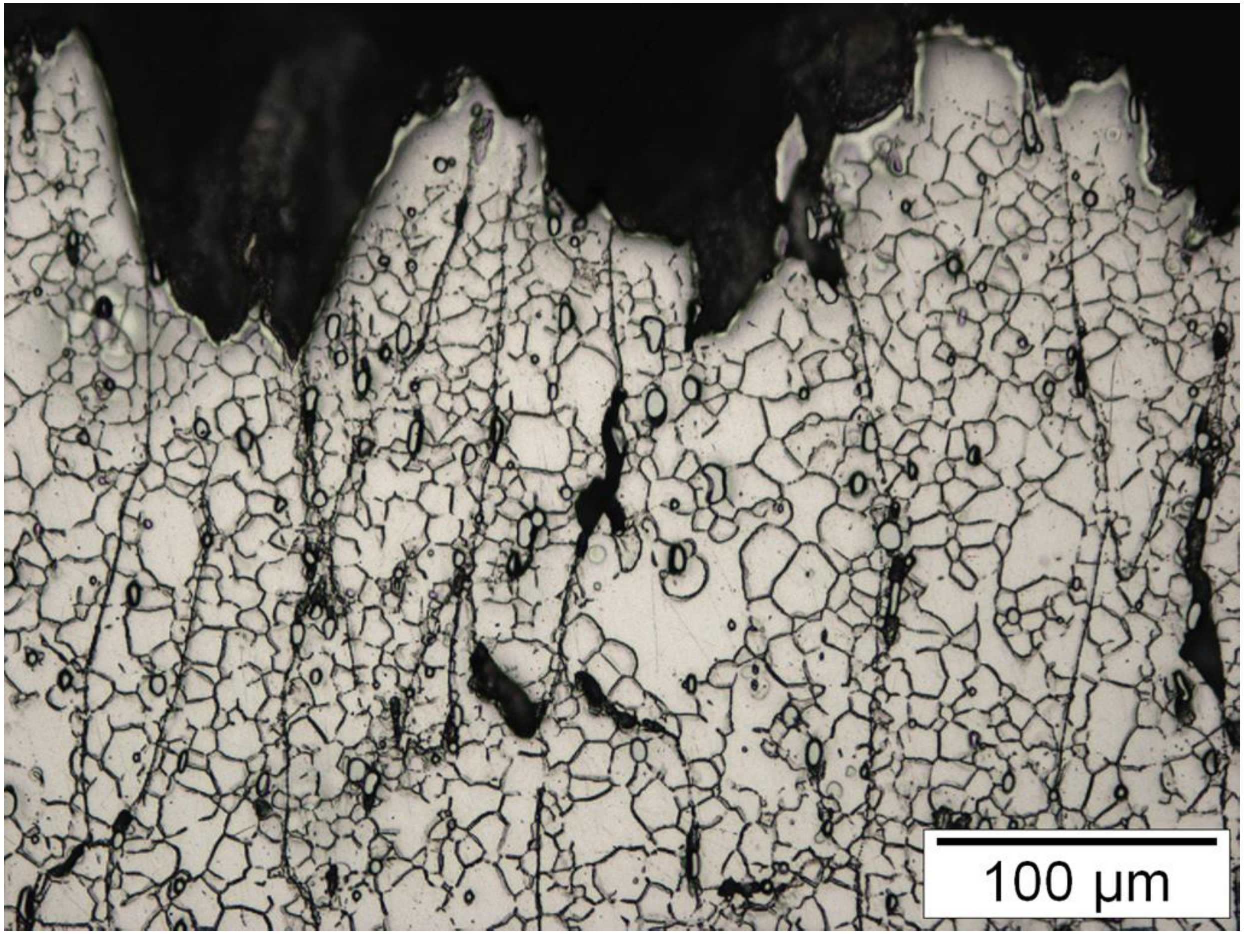
- Rate of ductility recovery and OC ZDR do not suggest crack sensitivity.

Hot Ductility Alloy 230 - True Stress



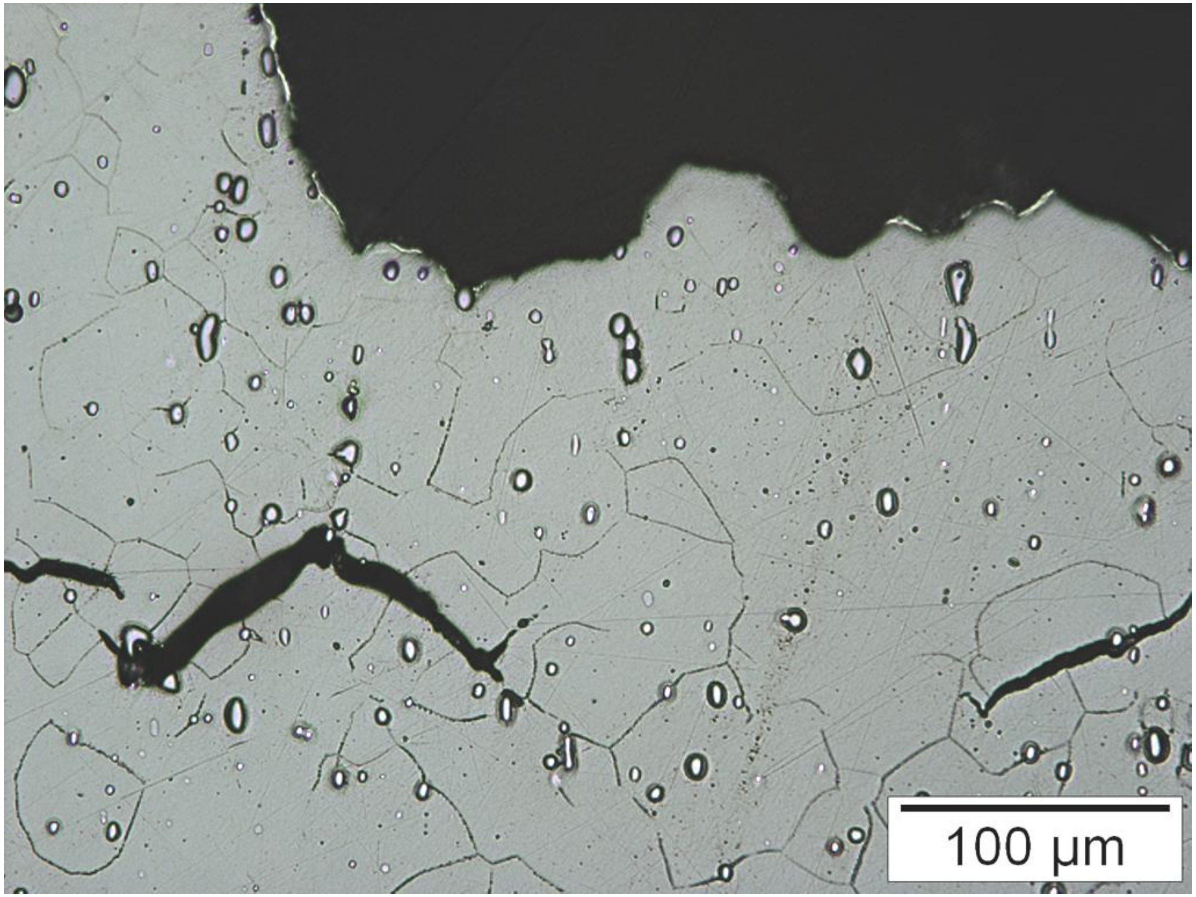
- Rate of strength recovery does not suggest crack sensitivity.

Failure Mode in DRX Region



•**Evidence of Dynamic DRX (1053°C OH).**

Failure Mode Above DRX Region



- Up to 1263°C OH, failure occurs in transgranular mode by decohesion of M_6C carbides and linking of the cracks between carbides.

Summary

- **Weldability issues with the pertinent alloys have been reviewed and preliminary results of our work on Haynes 25 have been presented.**
- **Further results on the mechanical properties and metallography on the EB welds are imminent.**
- **Hot-ductility experiments will commence within a few weeks. Aging studies on the effects of heat treatment using the Gleeble are also planned.**
- **MST-6 has extensive background in the welding metallurgy of the pertinent alloys.**
- **We also have considerable experience with the various welding processes to be used.**