A-USC Steam Cycle Turbine Materials

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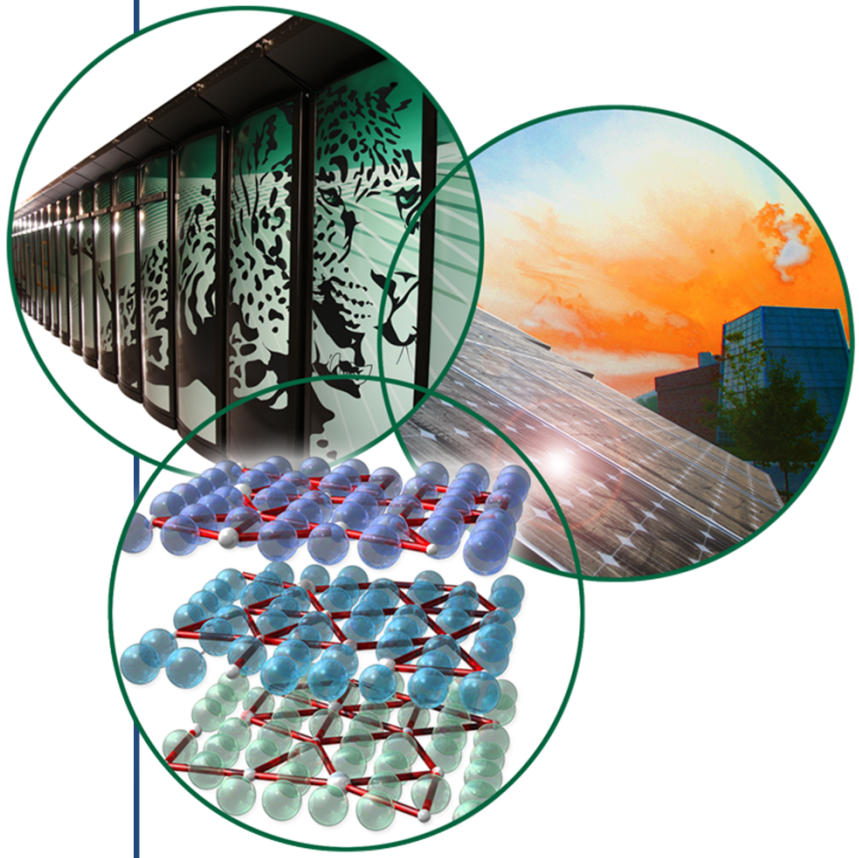


NETL 2015 Crosscutting Materials Review,
April 27-30, 2015

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

TASK 1 - FORGED TRIPLE-MELT HAYNES 282 ALLOY FROM GE – FATIGUE TESTING AT ORNL

SHYAM, MAZIASZ , HAWKINS, ROY, AND ERDMAN(ORNL), AND SAHA (GE)

Alloy 282 is a candidate material for A-USC turbine applications

- Haynes 282® is a relatively new alloy that has excellent fabricability and good creep and fatigue resistance
- Two microstructures
  - Bar/Billet/Plate Double Melted Product
  - Triple Melted Forged Disk
- Double Melted average grain size (with twins) = 13.6 ± 0.3 μm

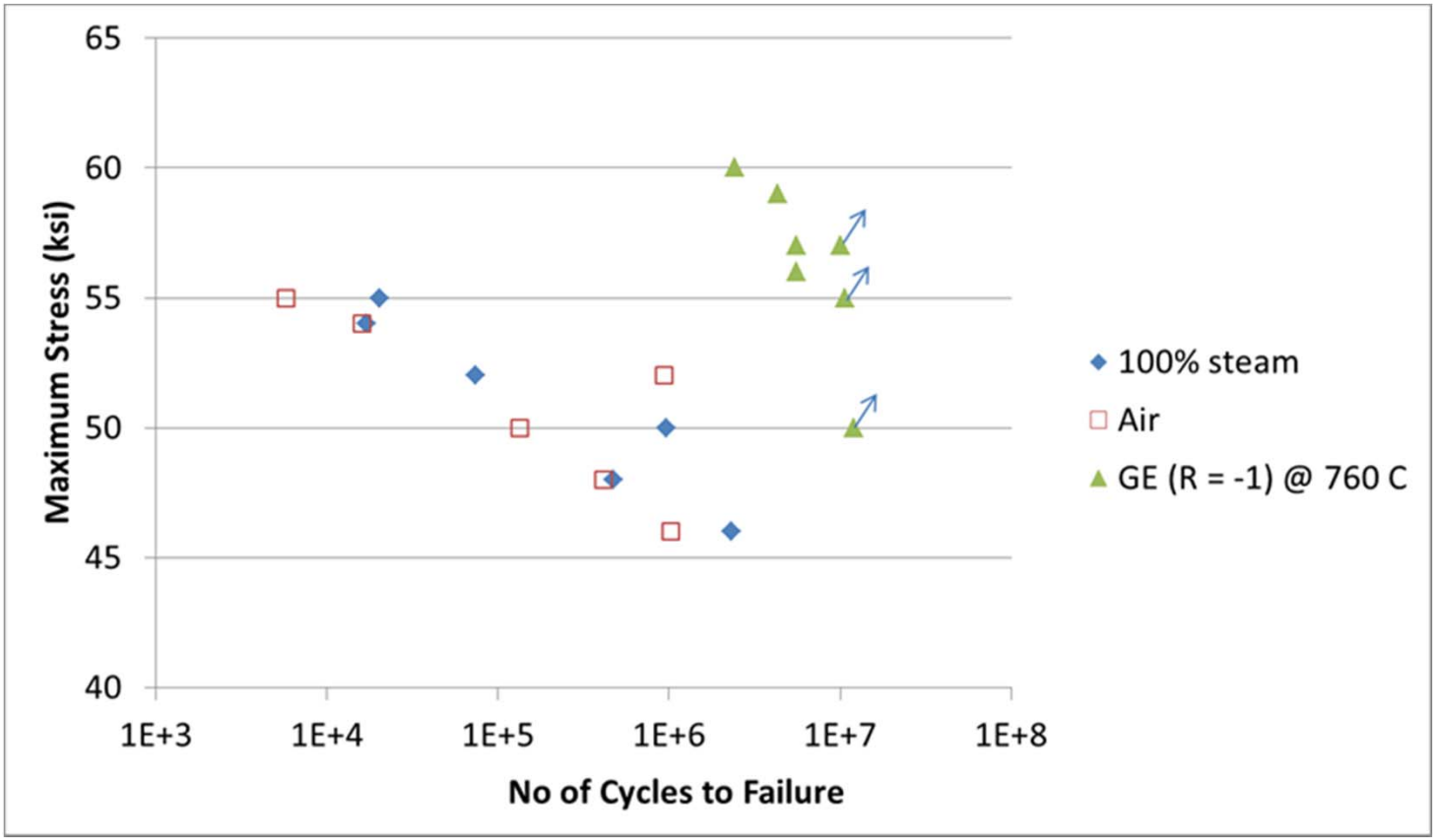
  Average grain size (without twins) = 29.4 ± 0.8 μm
- Triple Melted Average grain size (with twins) = 10.1 ± 0.2 μm

  Average grain size (without twins) = 16.5 ± 0.3 μm

Nominal Chemical Composition, Weight %										
Ni	Cr	Co	Mo	Ti	Al	Fe	Mn	Si	C	B
57**	20	10	8.5	2.1	1.5	1.5*	0.3*	0.15*	0.06	0.005

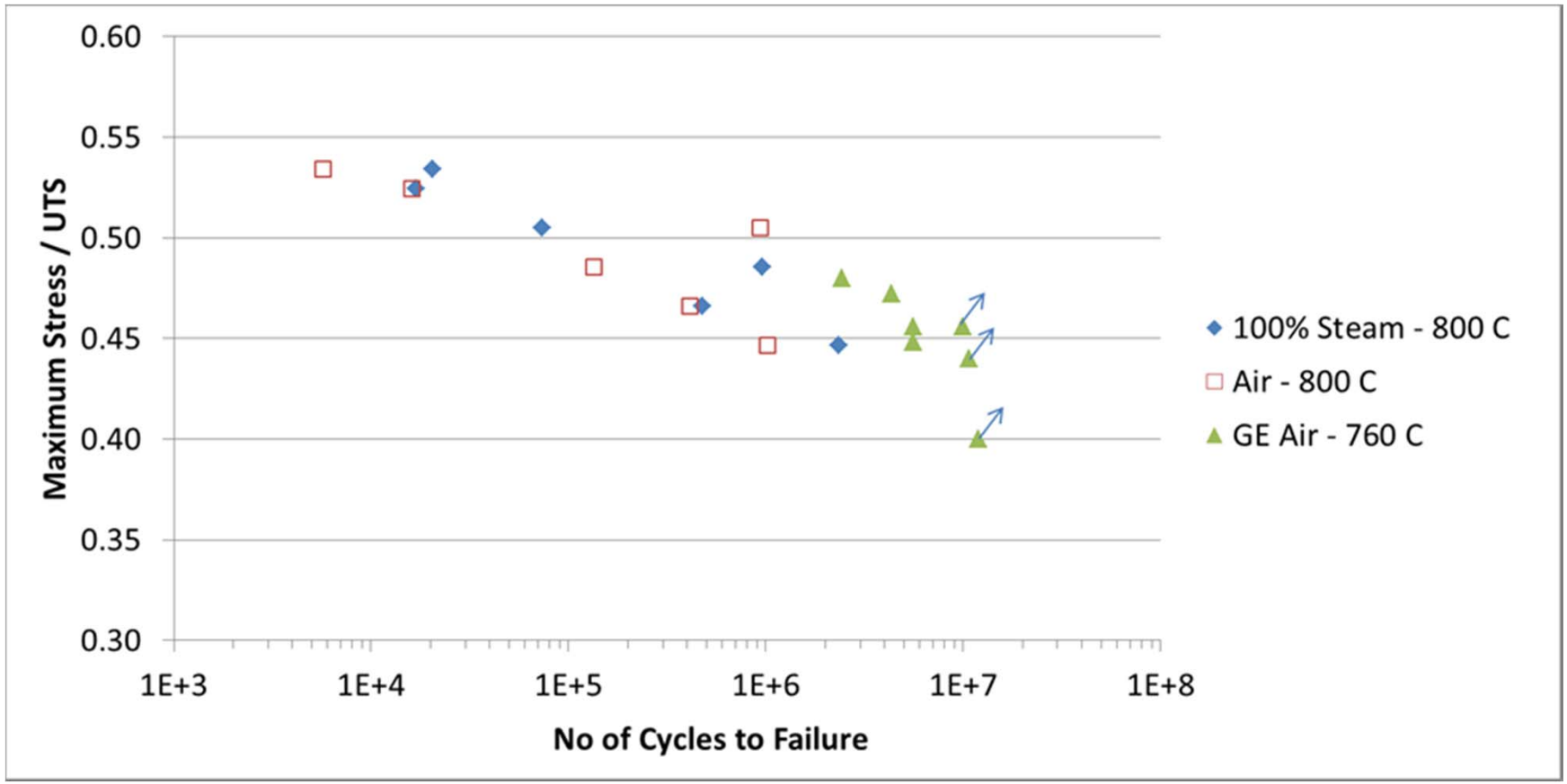
* Maximum ** Nickel as balance

Comparison of ORNL fatigue data with GE data on double melted alloy 282



- ORNL testing at 800^{o}C and 20 Hz sine wave
- GE testing at 760^{o}C and 50 Hz triangular wave
- All data at R = -1

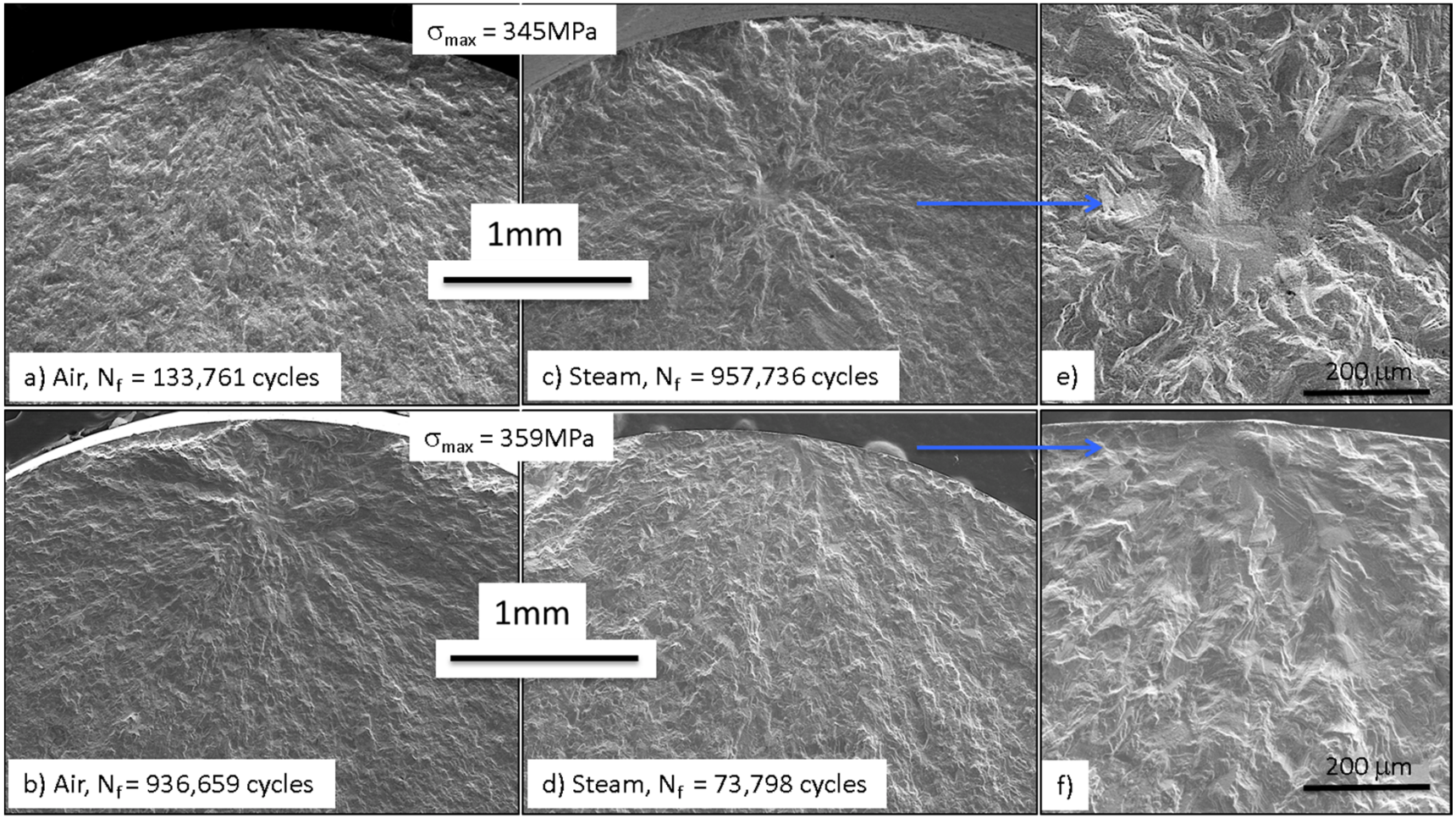
Correspondence in data is good when normalized with UTS at testing temperature



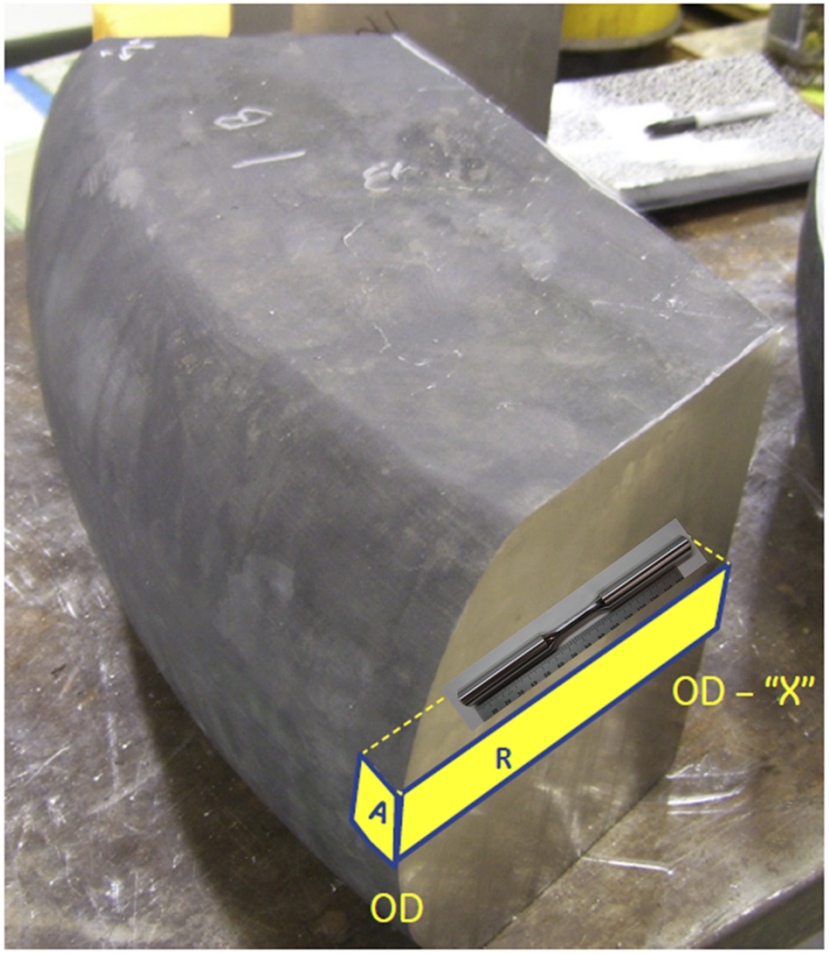
Average UTS at 1400 F (760C) = 125 ksi

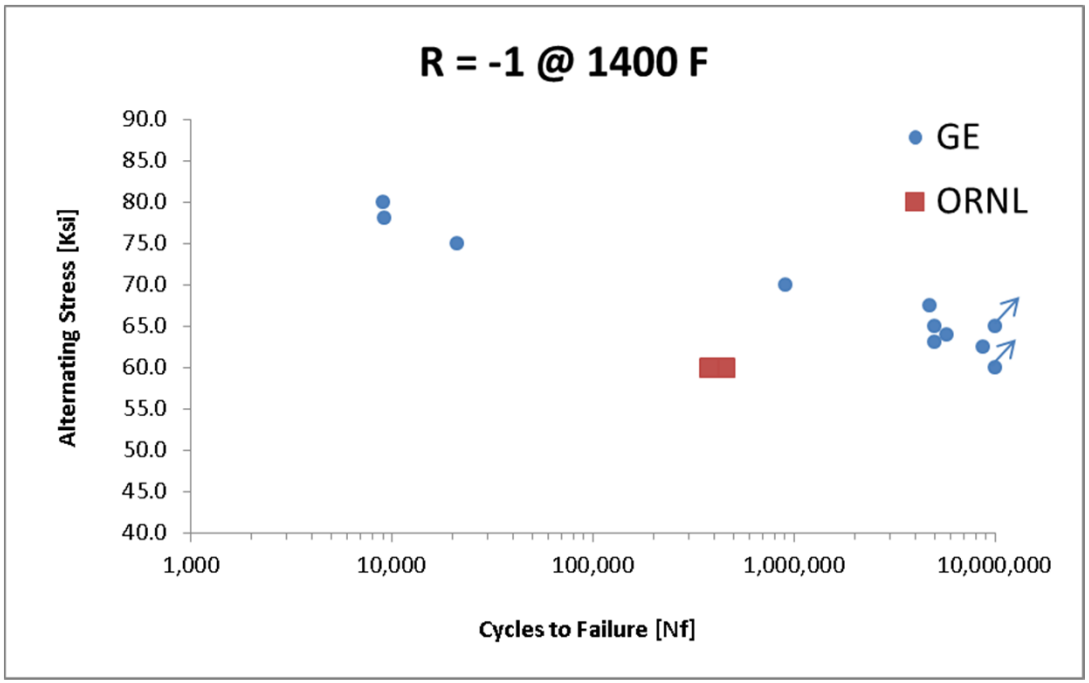
1472 F (800C) = 103 ksi

Higher lifetime is associated with subsurface failures regardless of air or steam testing



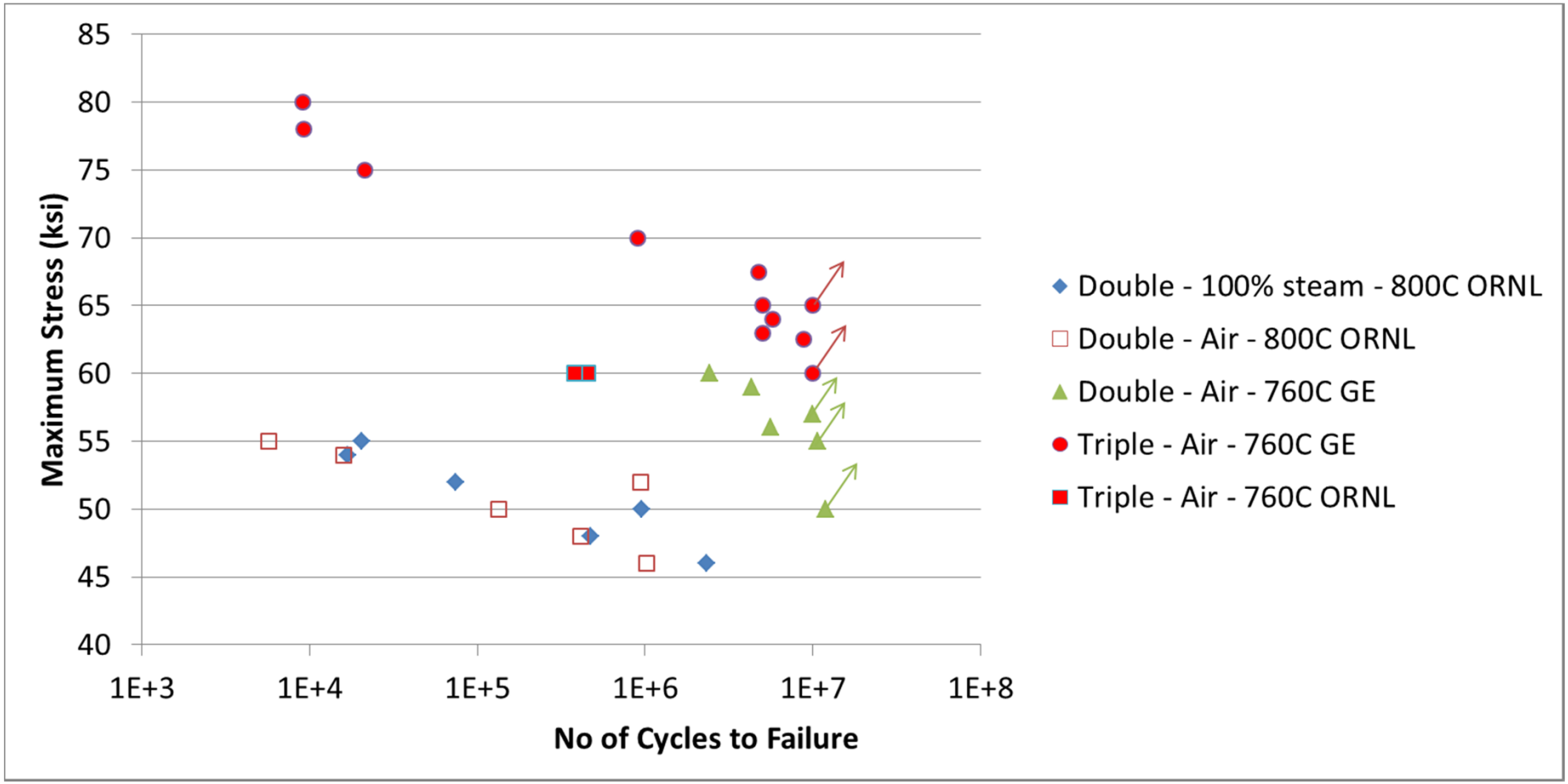
GE Specimens and data on triple melted **microstructure**





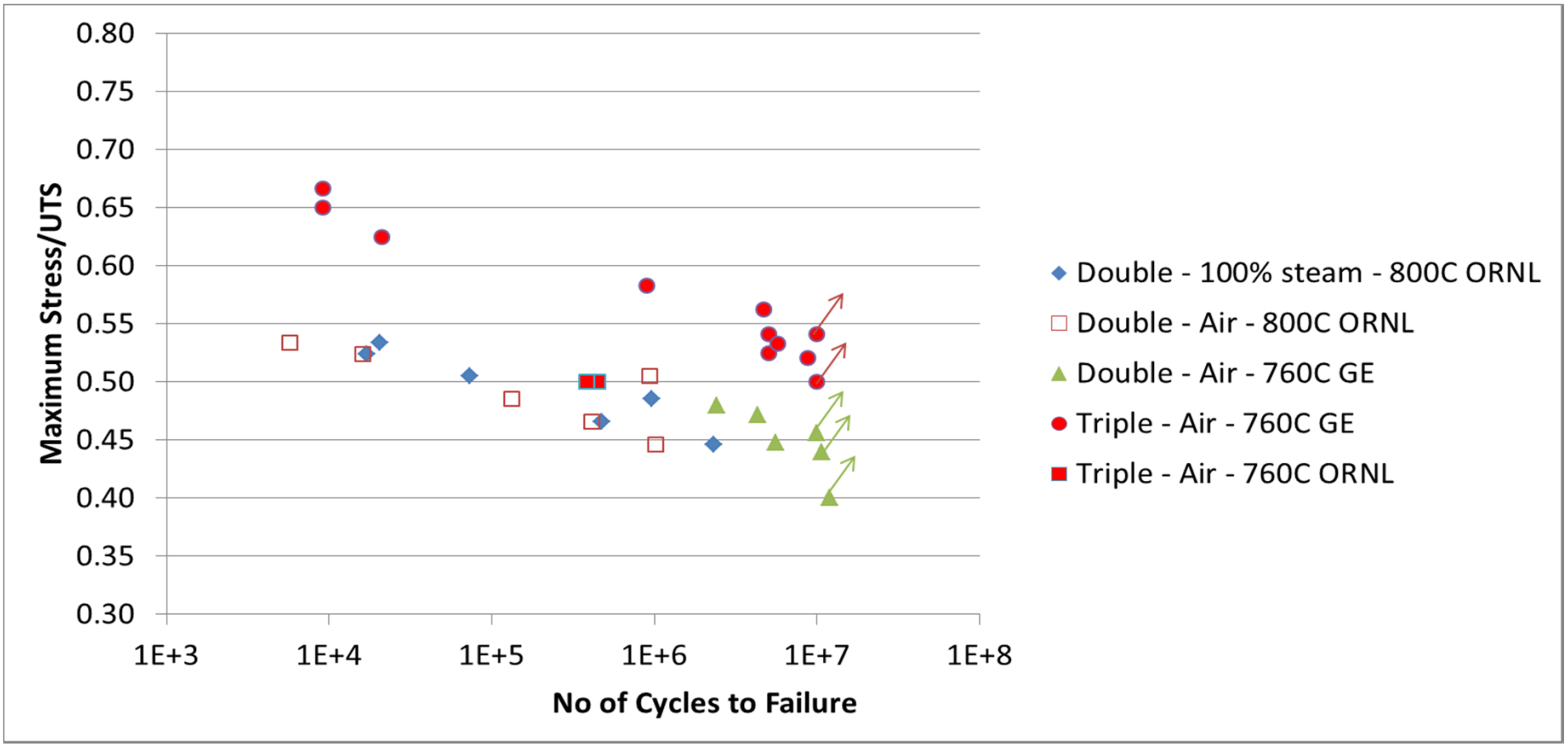
- Statistically significant difference between GE and ORNL data
- Large amount of time and energy expended in trying to find the source of differences (alignment, test procedure, heating procedure, HV, thermocouples etc.)
- Turns out ORNL and GE (Westmoreland) methods are quite similar so this is still not clear!

Summary slide for all R = -1 fatigue testing performed (on double/triple melt materials)



- Double melt data discussed in previous reports
- Triple melt data only generated in air so far

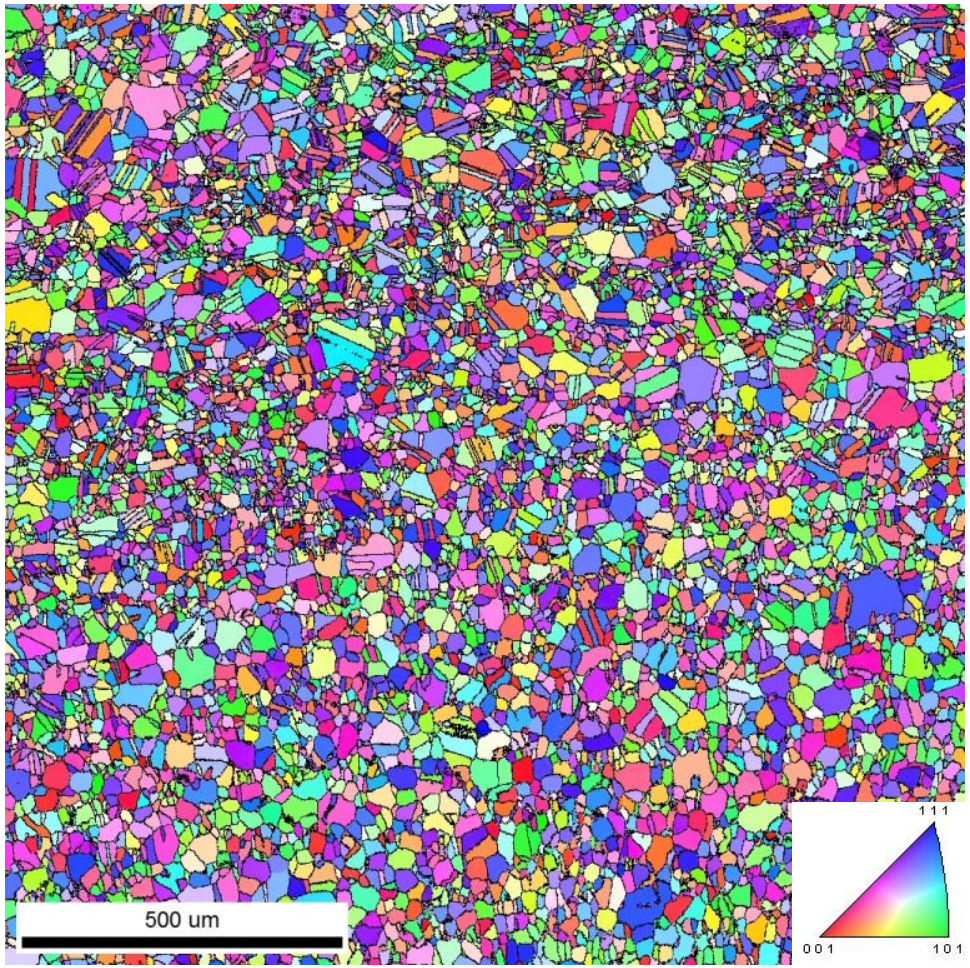
Compare double and triple melted material fatigue data (normalized)



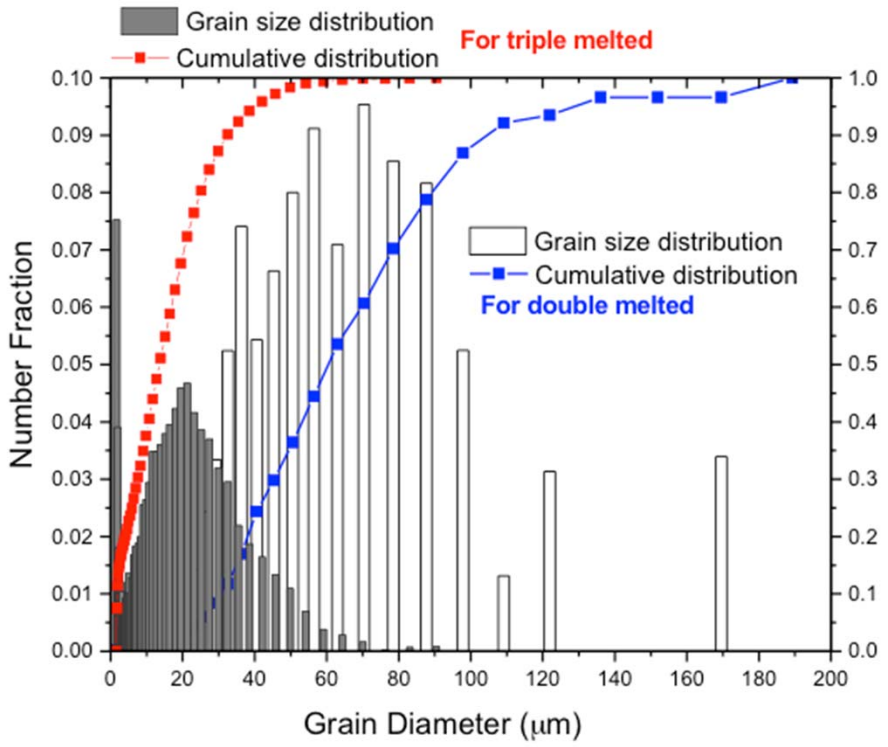
- After normalization, ORNL triple melt material fatigue data corresponds with other data better!
- Testing in air and steam will now continue at ORNL for triple melt material

EBSD on triple melted microstructure (Grain tolerance angle 5º)

- Triple melted material is much finer and has a lower twin density than the double melted alloy 282



Average grain size (with twins) = 10.1 ± 0.2 µm
Average grain size (without twins) = 16.5 ± 0.3 µm
* GS calculated with number fractions



Summary and Conclusions

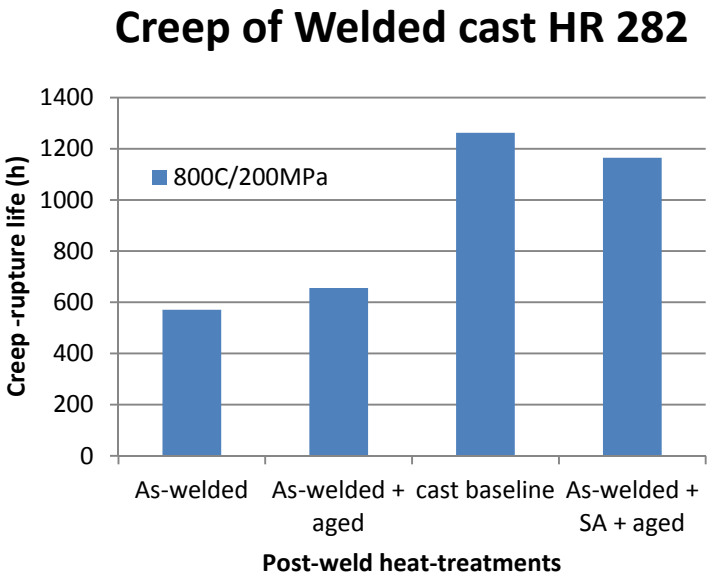
- One of a kind fatigue testing setup (100% steam and temperatures up to 900^{o}C) developed
- Steam fatigue testing on double-melted alloy 282 performed in air and 100% steam at 800^{o}C
- Failure lifetime variability related to failure location (surface versus subsurface)
- No significant effect of steam environment
- Triple melted disc specimens show improved fatigue lifetime at 760^{o}C

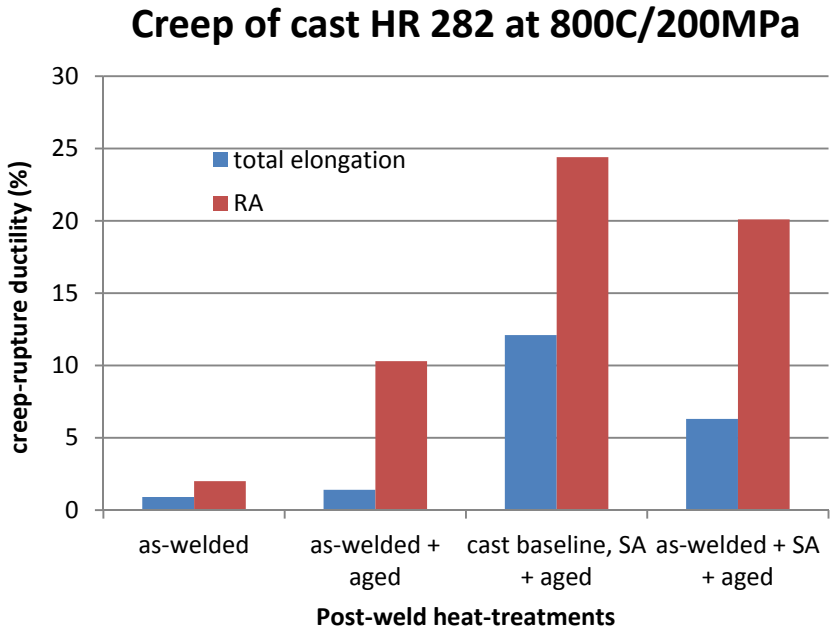
TASK 2 - WELDED CAST HR 282 ALLOY

MAZIASZ, MOSER, UNOCIC, YANG (ORNL), JABLONSKI (NETL/ALBANY)

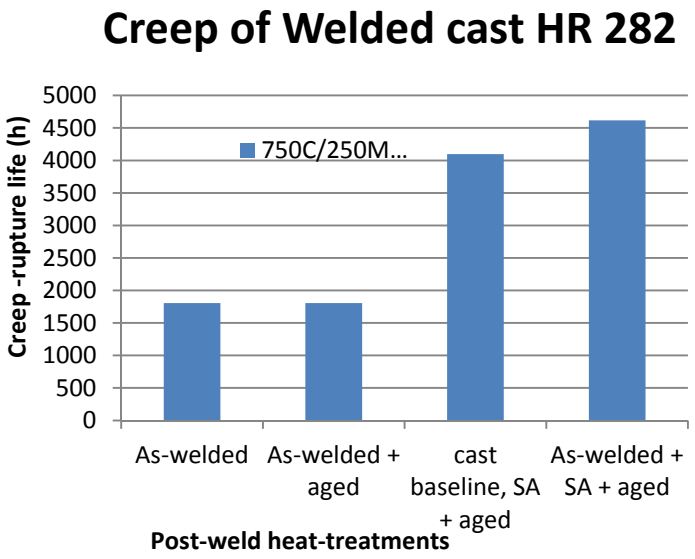
New work includes analysis of creep-ductility and microstructure analysis of fusion zone of creep specimens at 800C/200MPa in as-welded and in fully heat-treated conditions, with Pandat calculations to help interpret the microstructure

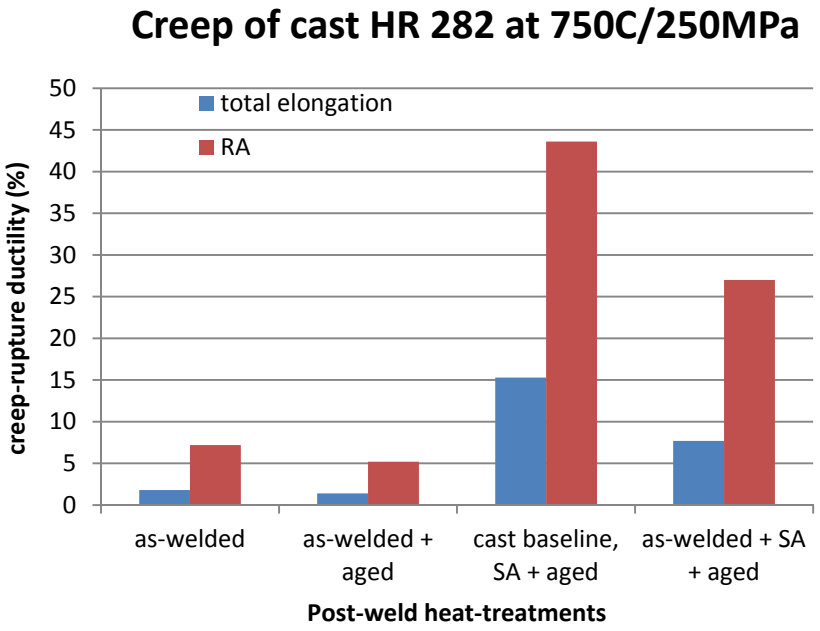
The Creep-Rupture Ductility Shows a Larger Effect of HT Than Does Rupture Life of Welded Cast HR 282 – 800°C/200MPa





The Creep-Rupture Ductility Shows a Larger Effect of HT Than Does Rupture Life of Welded Cast HR 282 – 750°C/250MPa



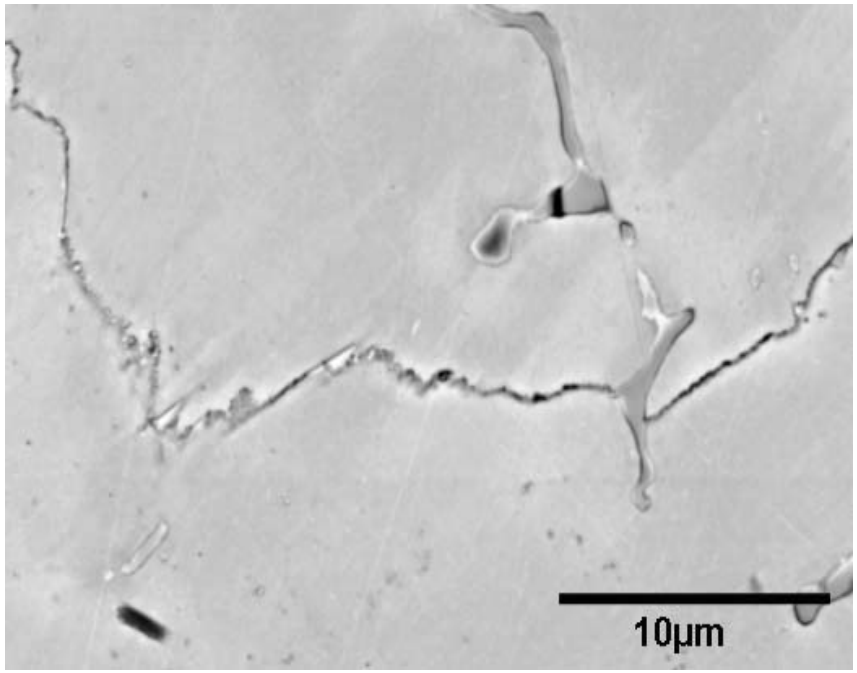


Repeat Creep-Rupture Testing of Fully-Heat Treated Cast and Welded Haynes 282 Alloy

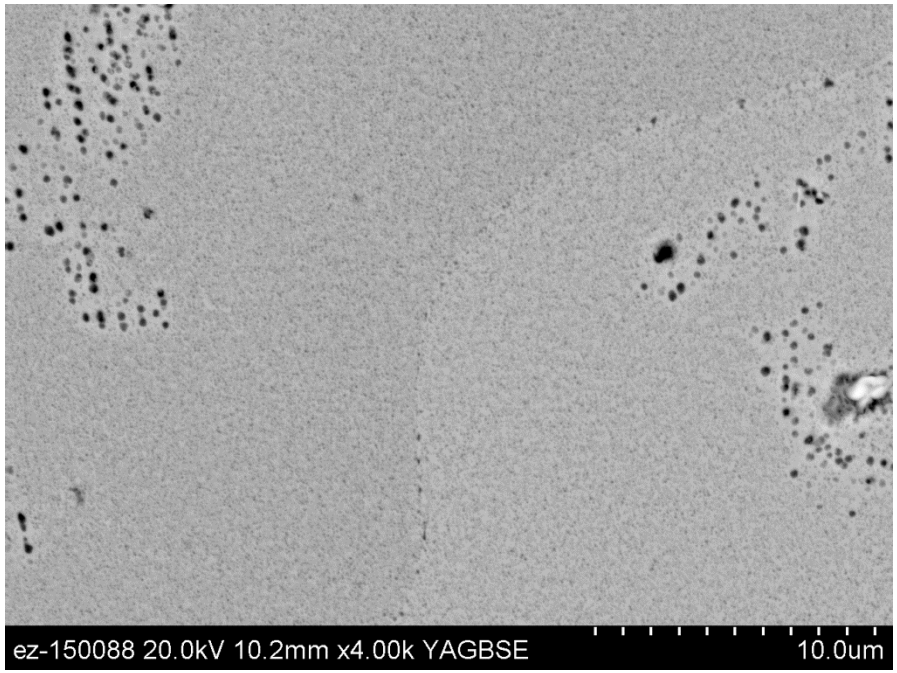
- 800°C/200 MPa – 2207h rupture
- 750°C/250 MPa – 3095h and still running

Analysis of the Fusion Zones of the Welded Cast HR 282 Reveal The Effects of Heat Treatment

Fusion Zone, as-welded



Fusion Zone, fully heat-treated



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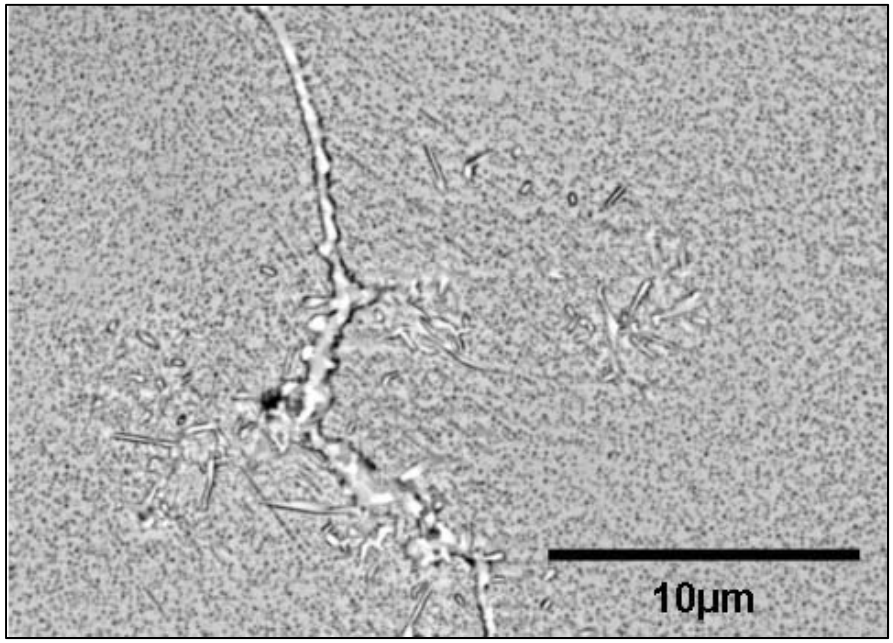
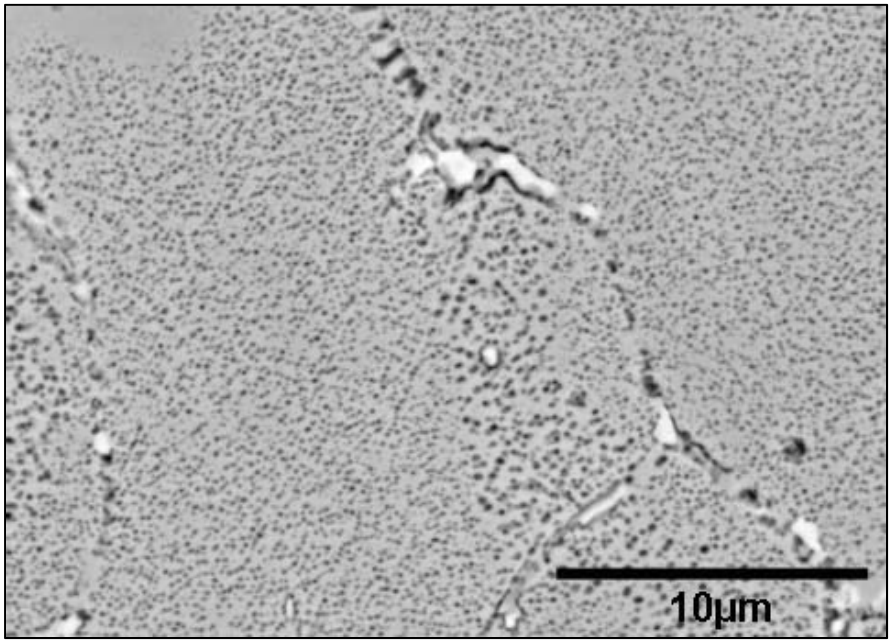


590h

Fusion Zone, fully heat-treated



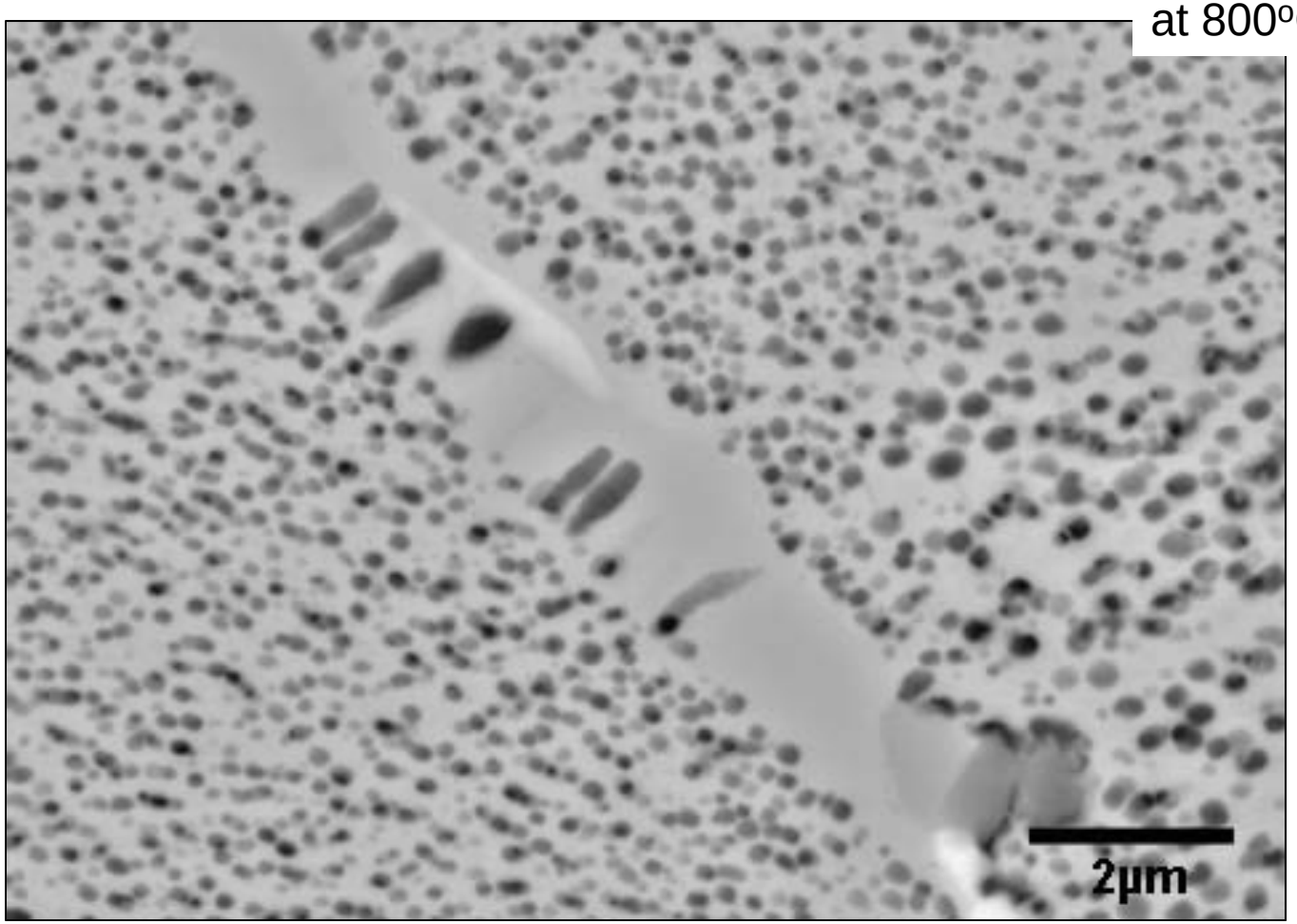
1250h

Creep tested at 800^{o}C/200MPa

Fully heat treated cast HR 282 developed gamma prime denuded zones at GBs

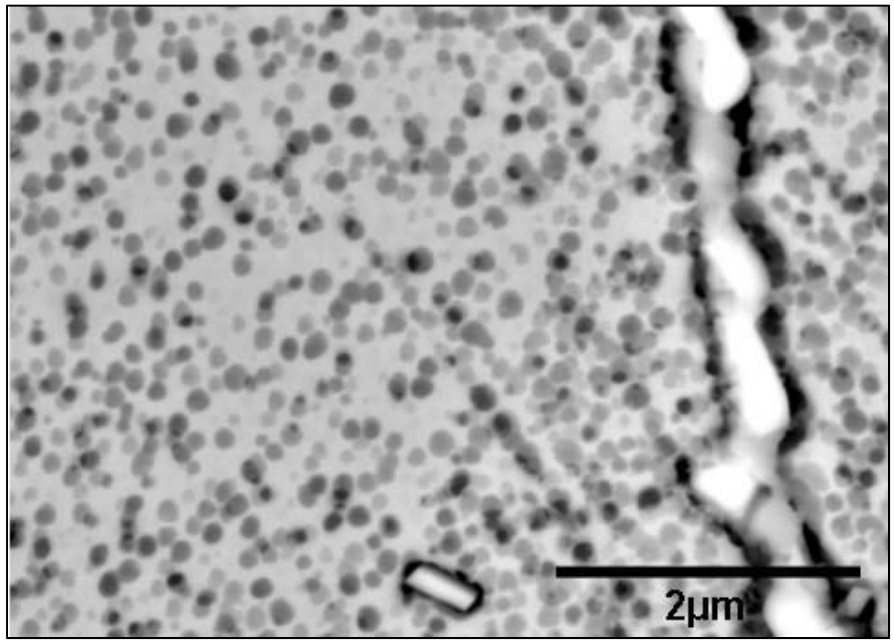
Fusion Zone, fully heat-treated

Creep tested
at 800^{o}C/200MPa



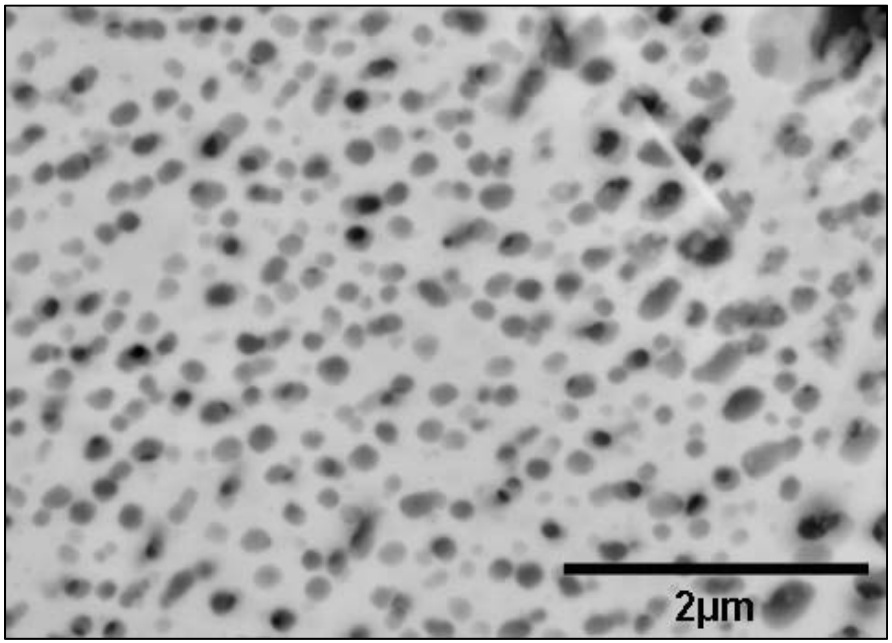
Gamma Prime Structures of the Welded Cast HR 282 specimens are similar

Fusion Zone, as-welded



590h

Fusion Zone, fully heat-treated

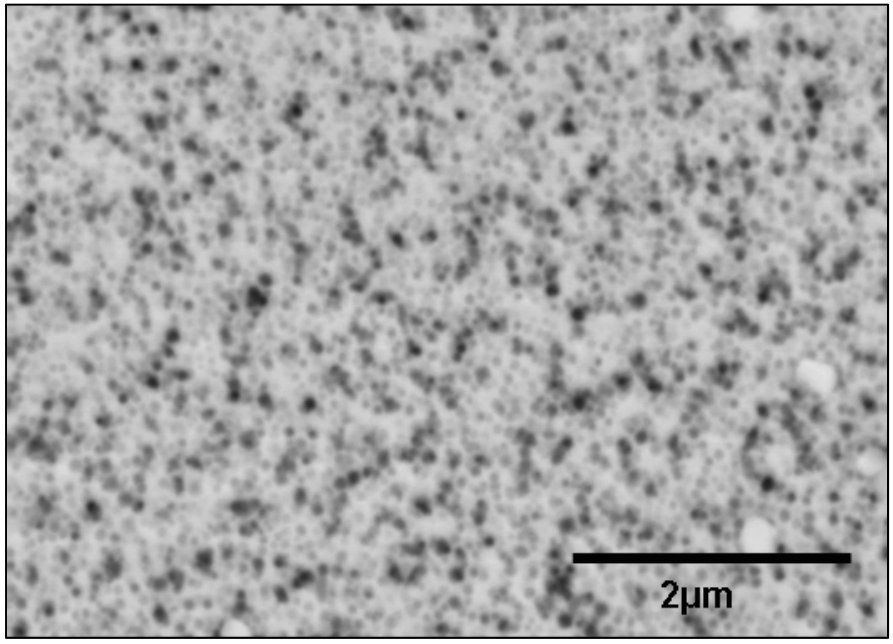


1250h

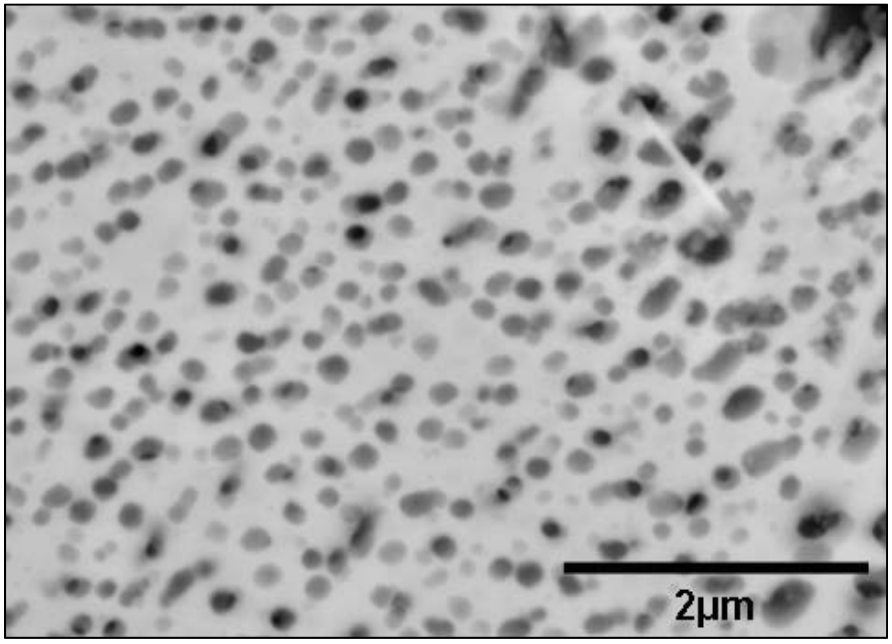
Creep tested at 800^{o}C/200MPa

Gamma Prime Coarsens During Creep in the Welded Cast HR 282, Fully Heat-Treated

Fusion Zone, fully heat-treated

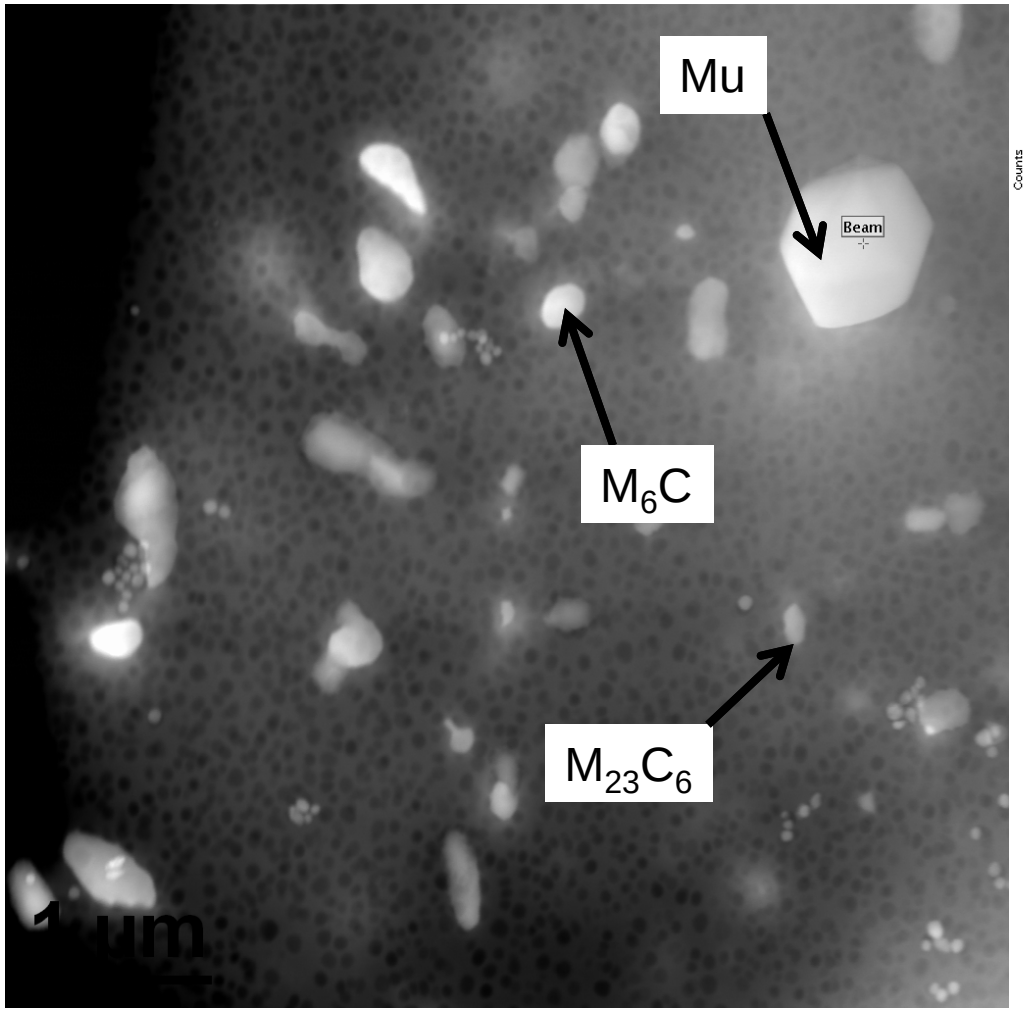


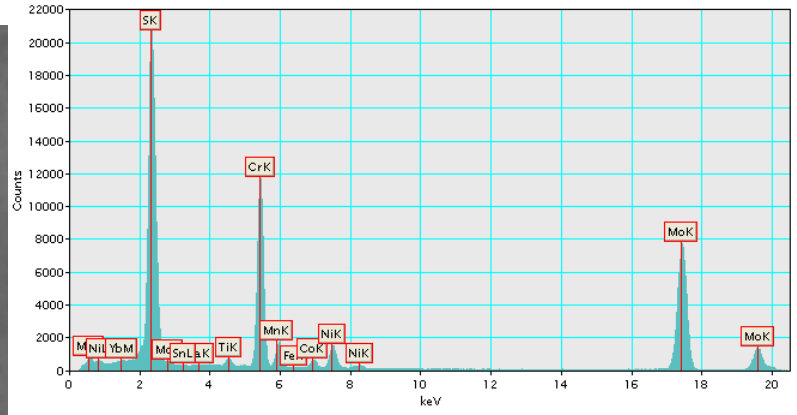
As heat-treated



Creep tested at 800°C/200MPa 1250h

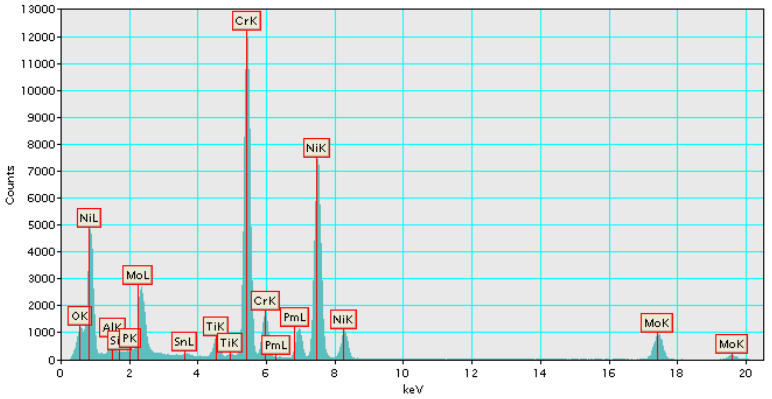
TEM/AEM identifies phases in welded cast HR 282, fully heat-treated and creep tested (800°C/200MPa)



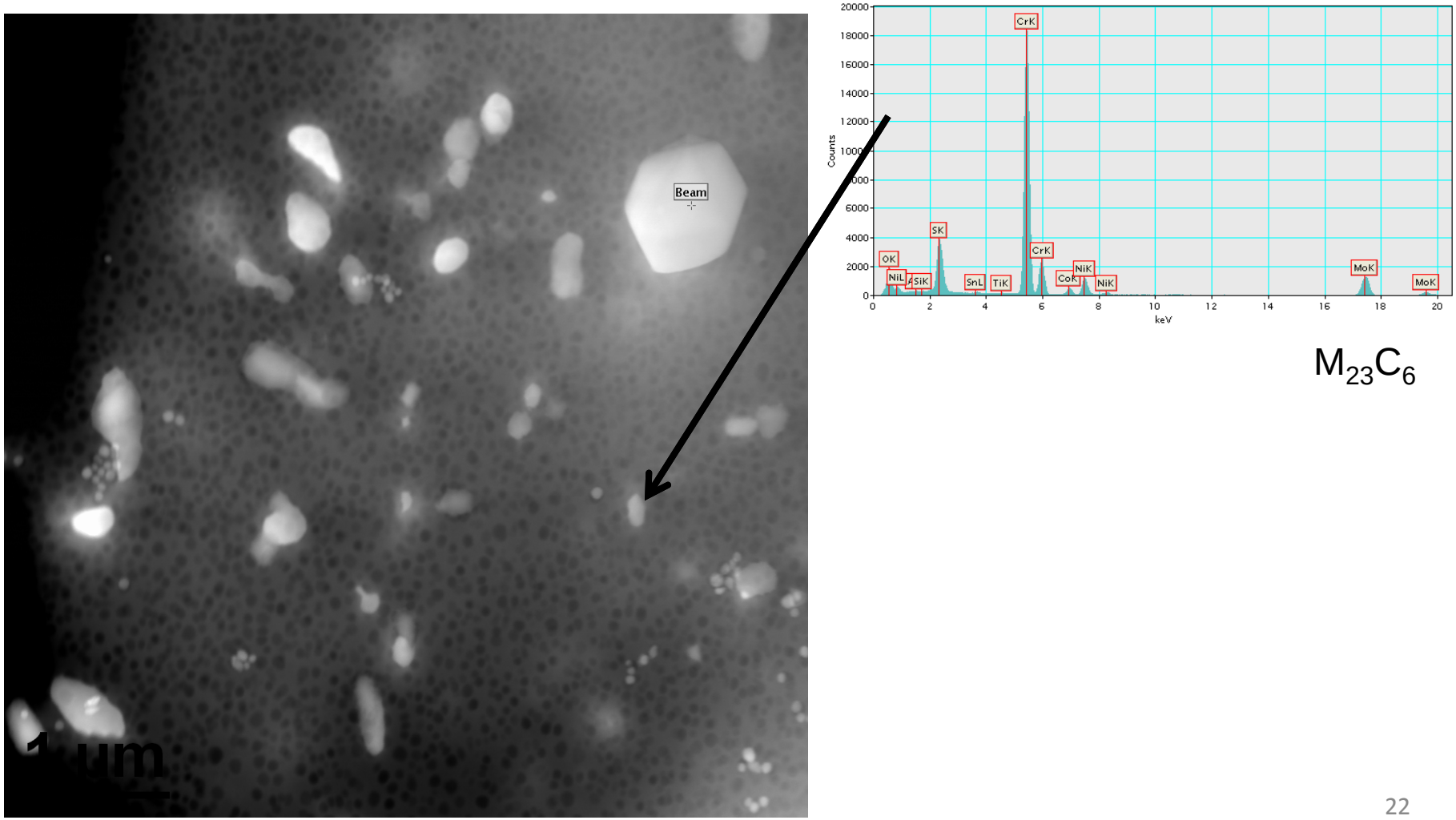


Mu

M_6C

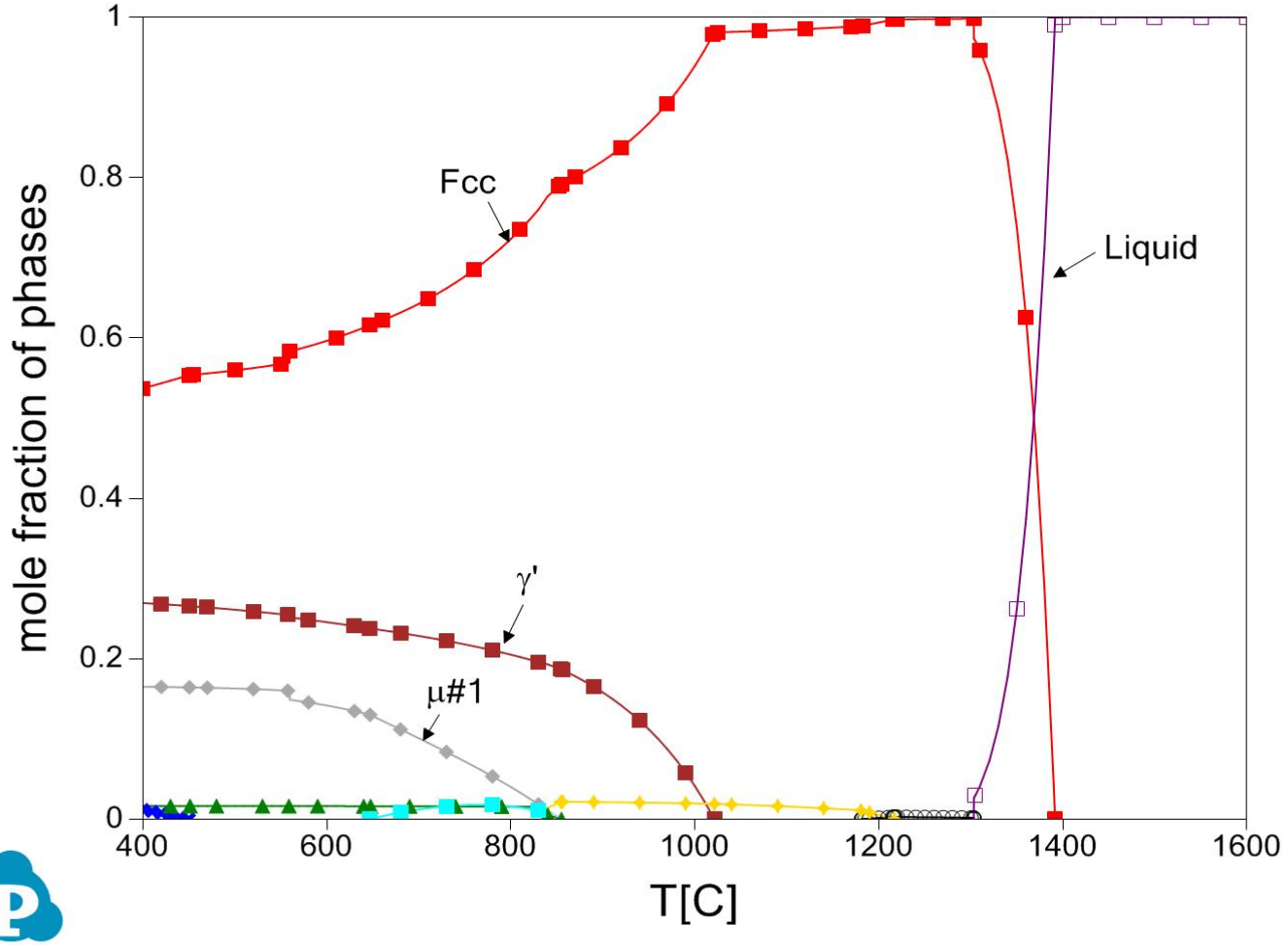


TEM/AEM identifies phases in welded cast HR 282, fully heat-treated and creep tested (800°C/200MPa)

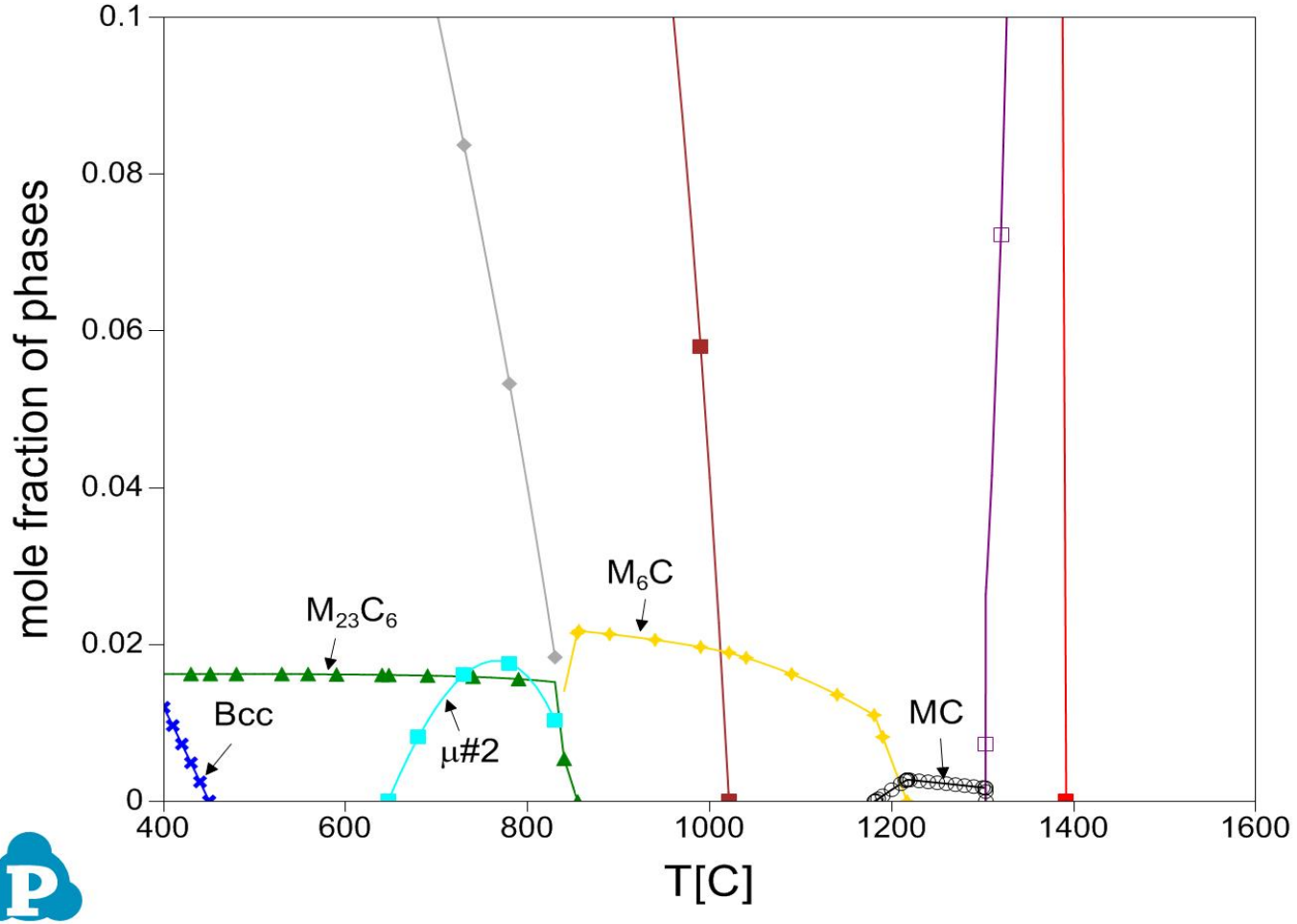


$M_{23}C_6$

Pandat-PanNi Calculations for HR 282 Alloy



Enlarged Axis for Pandat Calculations for HR 282 Alloy



TASK 3 - PM HAYNES 282 ALLOY, HIPED AND HEAT-TREATED

MAZIASZ, MOSER, UNOCIC, STEPHENS, (ORNL)
PURGERT, SHEPPARD, AND FLOWEN (EIO)

PM HR 282 HIPed by BodyCote and heat-treated

PM HR 282 atomized by Carpenter Technology

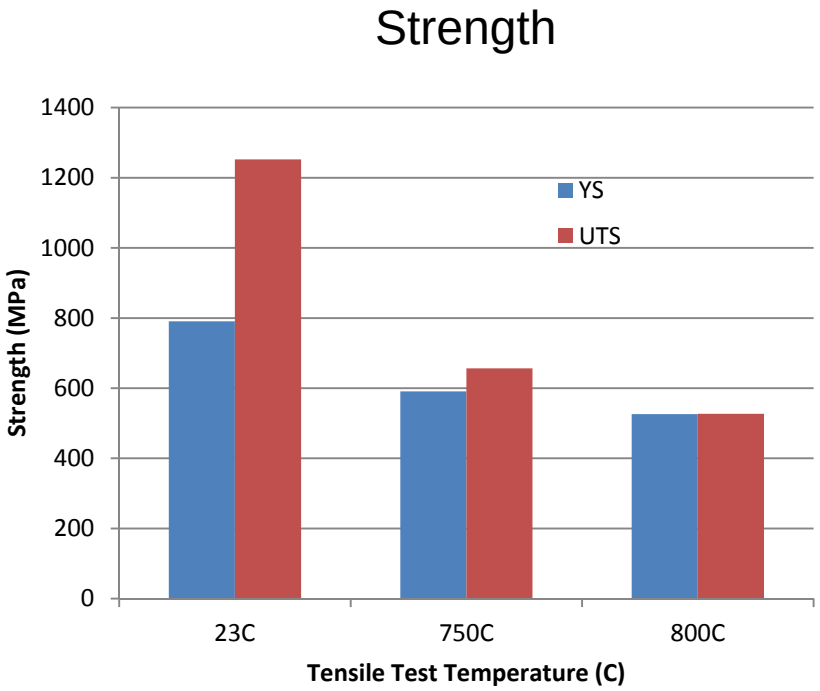
PM HR282, HIPed and Heat-Treated

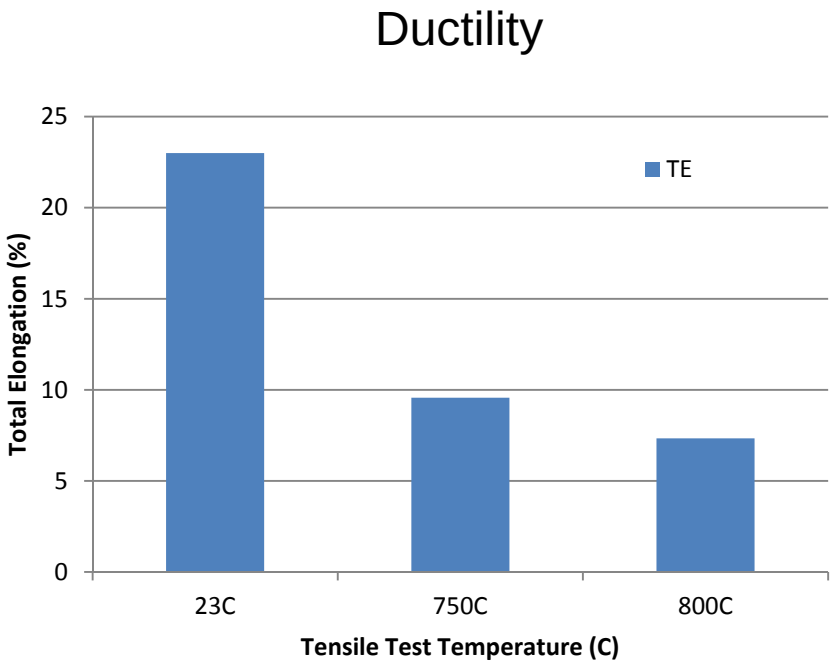
- 995 lb of HR282 melt yielded 725 lb of 60 mesh powder
- **HIP** – 1160°C for 4h at 14.75 ksi
- **HT** – 1121-1149°C for 12h + 1010°C for 2h + 788°C for 16h

HIPed PM HR282 can/ingot

HIPed PM HR282 can/ingot – ORNL specimens

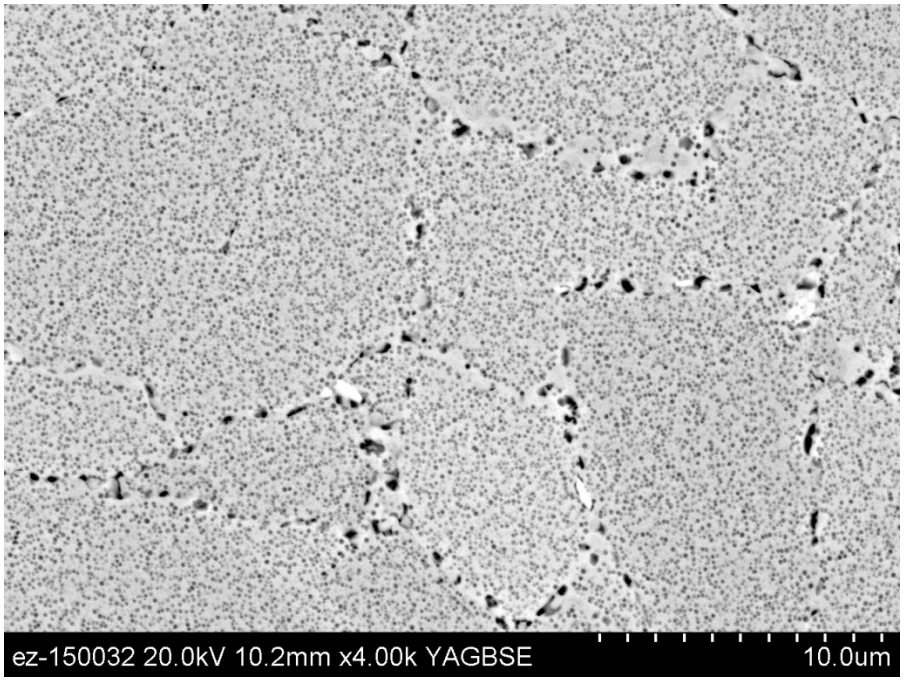
HIPed PM HR282 alloy shows good strength, but lower ductility at 750-800°C

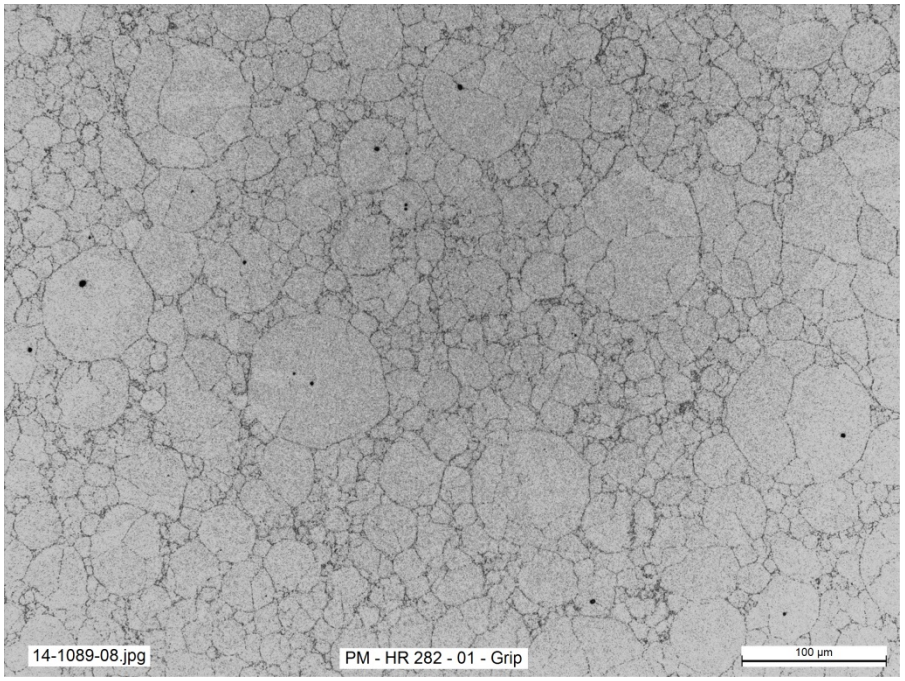




HIPed PM HR282 HT establishes grain boundary precipitates and gamma prime

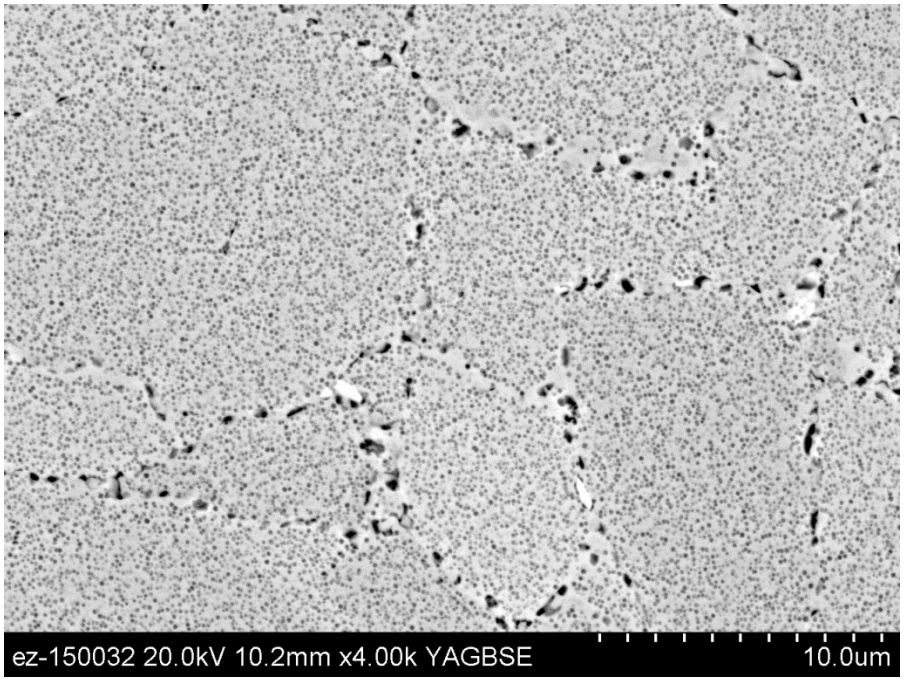
HIPed PM HR282

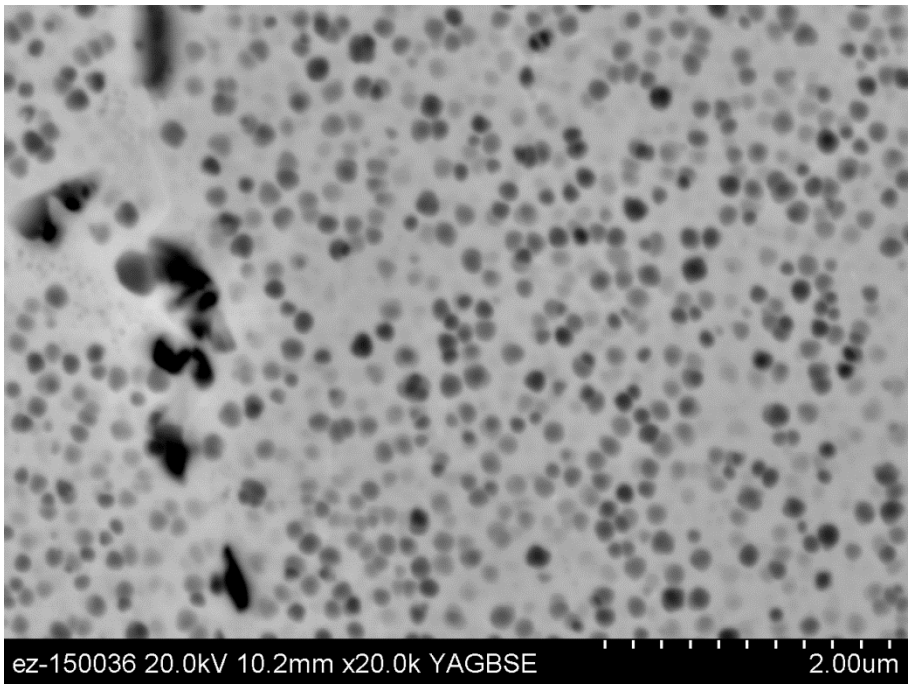




HIPed PM HR282 HT establishes grain boundary precipitates and gamma prime

HIPed PM HR282





HIPed PM HR 282 - Creep-Rupture Testing is in Progress

- 800^{o}C – creep at 200 MPa (46h)
- 800^{o}C – creep at 200 MPa (77h)
- 800^{o}C – creep of cast at 200 MPa (1250-2210h)
- 750^{o}C – creep at 200 MPa (773h)
- 750^{o}C – creep at 250 MPa (341h)
- 750^{o}C – creep of cast at 250 MPa (4500 h)

Summary

- GE forged triple-melt Haynes 282 alloy HCF testing is in progress at ORNL, and ORNL data have lower fatigue stress than GE data at 760^{o}C
- Repeat creep testing is in progress on cast and welded HR 282 in the fully treated condition, and data is as good as or better than previous data
- TEM/AEM analysis of grain boundary phases in cast and welded creep tested specimens(800^{o}C/200MPa) shows heavy precipitation embrittles grain boundaries without full heat treatment

Summary

- GE forged triple-melt Haynes 282 alloy specimens have been supplied to ORNL for long-term (>10,000 h) creep testing, which will begin next quarter.
- GE will supply cast Haynes 282 alloy specimens from large valve-body casting for creep and microstructural analysis

FY2015 Milestones

- Complete creep-rupture testing of welds of cast Haynes 282 alloy – Jan, 2015, revised to June, 2015
- Complete plan on how ORNL will support A-USC efforts on COMTEST – March, 2015, completed
- Complete initial fatigue, steam effects and microstructural analysis for GE large forging of Haynes 282 alloy – July, 2015, on track
- Begin creep-rupture and mechanical properties testing and microstructural analysis of GE large casting of Haynes 282 alloy – Aug., 2015, on track