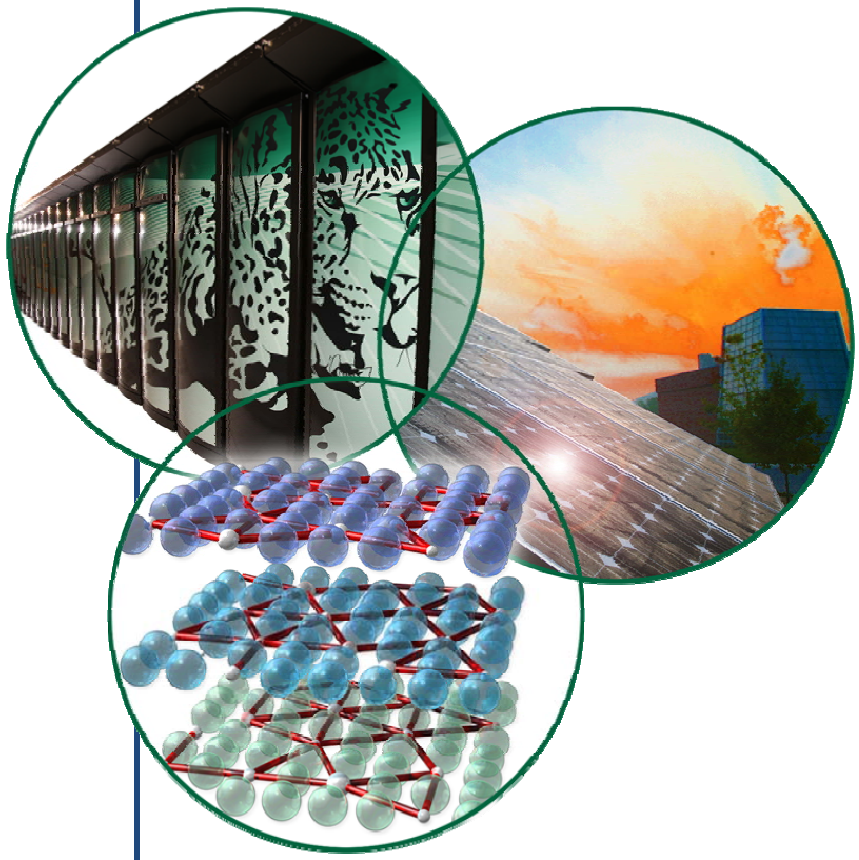
A-USC Steam Cycle Turbine Materials



Phil Maziasz and Amit Shyam – ORNL

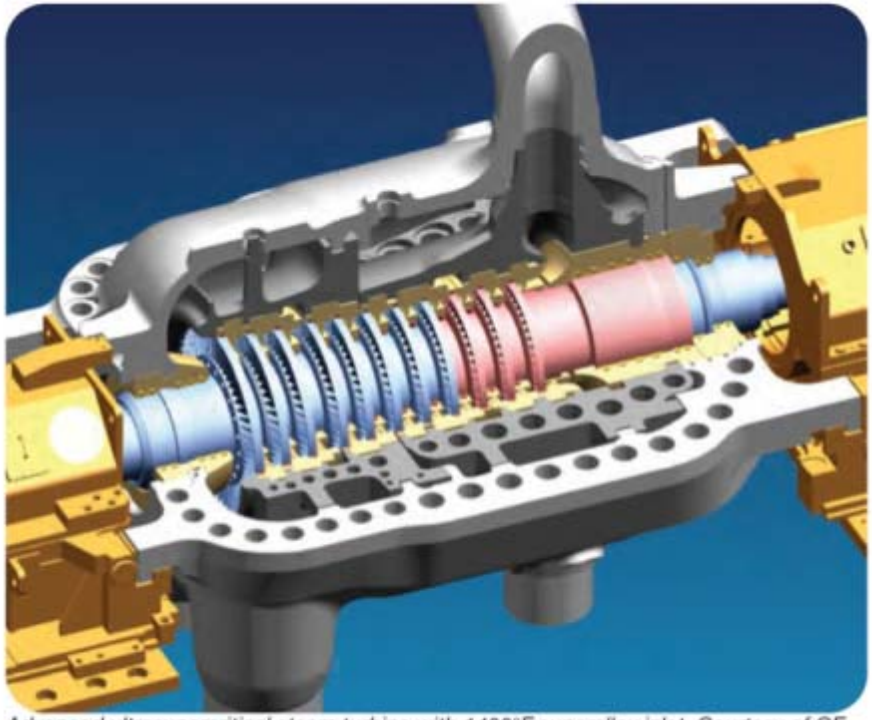
NETL 2016 Crosscutting Materials Review,
April 18-21, 2016

U.S. DEPARTMENT OF ENERGY

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

Background – Advanced Ultrasupercritical (A-USC) Steam Power Plants

From Schwant et al., AM&P 2013.



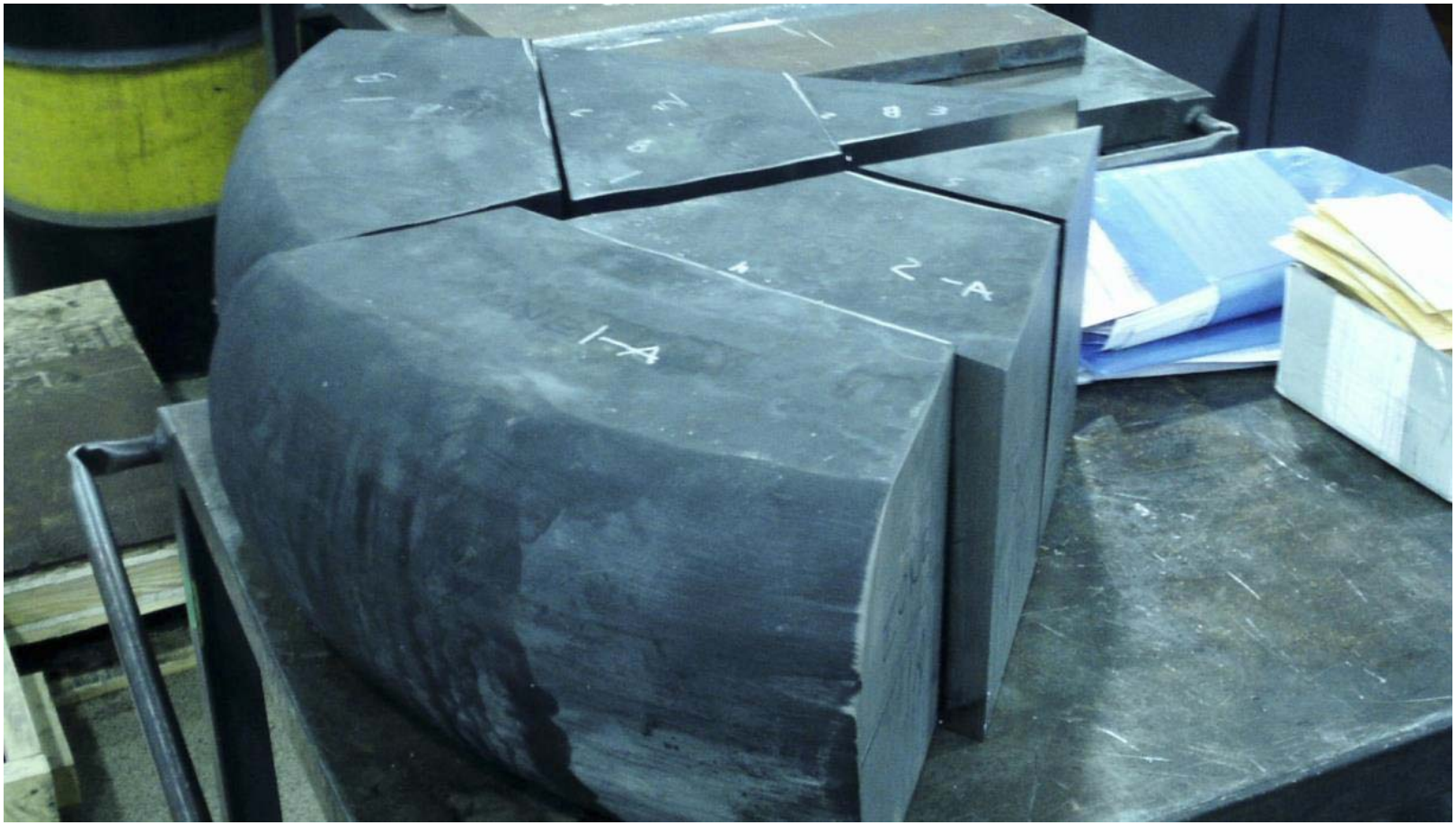
Advanced ultrasupercritical steam turbine with 1400°F superalloy inlet. Courtesy of GE Power & Water.

- **Advanced Ultrasupercritical (A-USC) steam power plant technology requires operation at maximum temperature of 760°C (1400°F) and 35 MPa (5000 psi) pressure.**
- **Materials technology is being developed to meet demands**

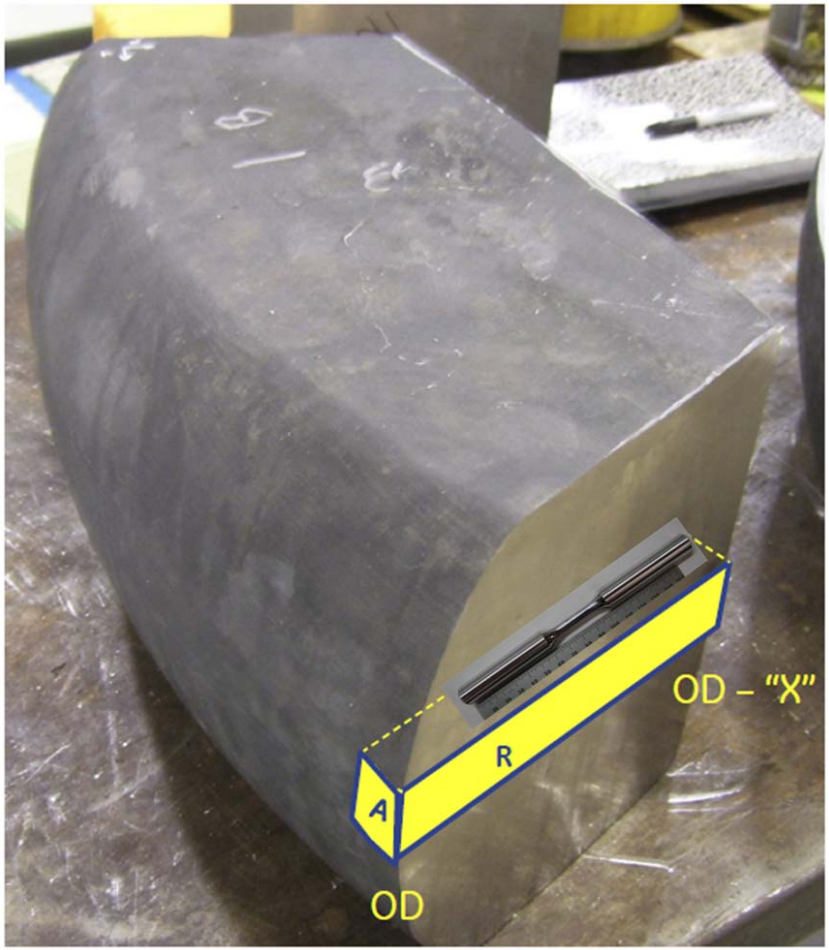
TASK 1 - FORGED TRIPLE-MELT HAYNES 282 ALLOY FROM GE – FATIGUE TESTING AT ORNL

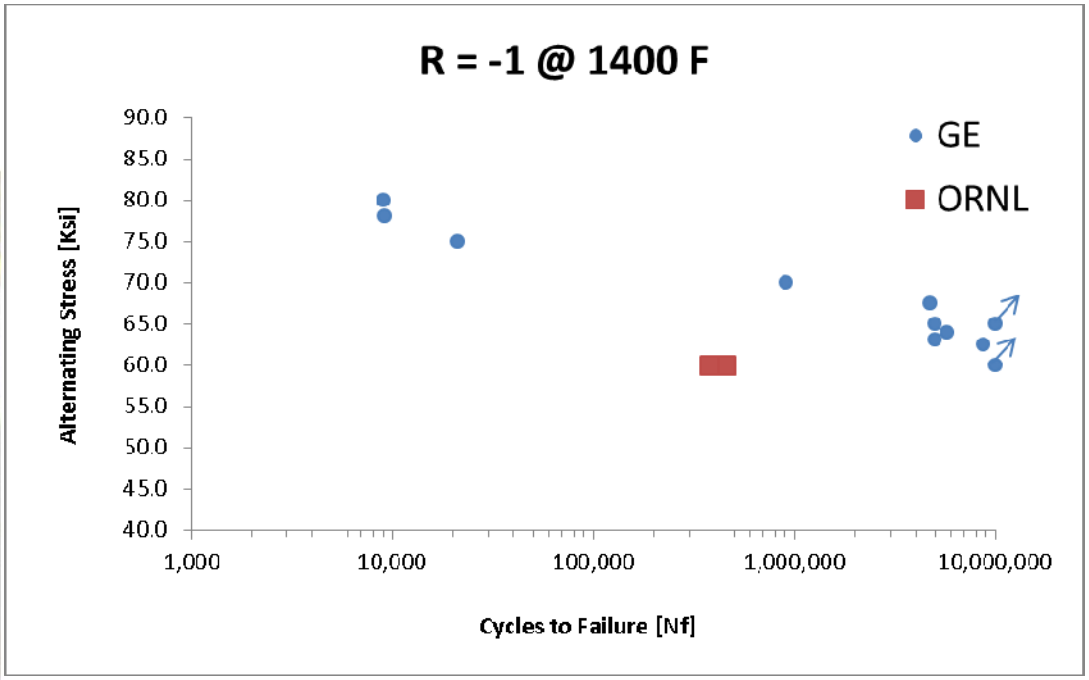
SHYAM, MAZIASZ , HAWKINS, AND ERDMAN(ORNL), AND SAHA (GE)

GE Triple-melted a 10,000 lb ingot and forged it into a disc for studies relevant to a rotor component



GE Specimens and data on triple melted microstructure

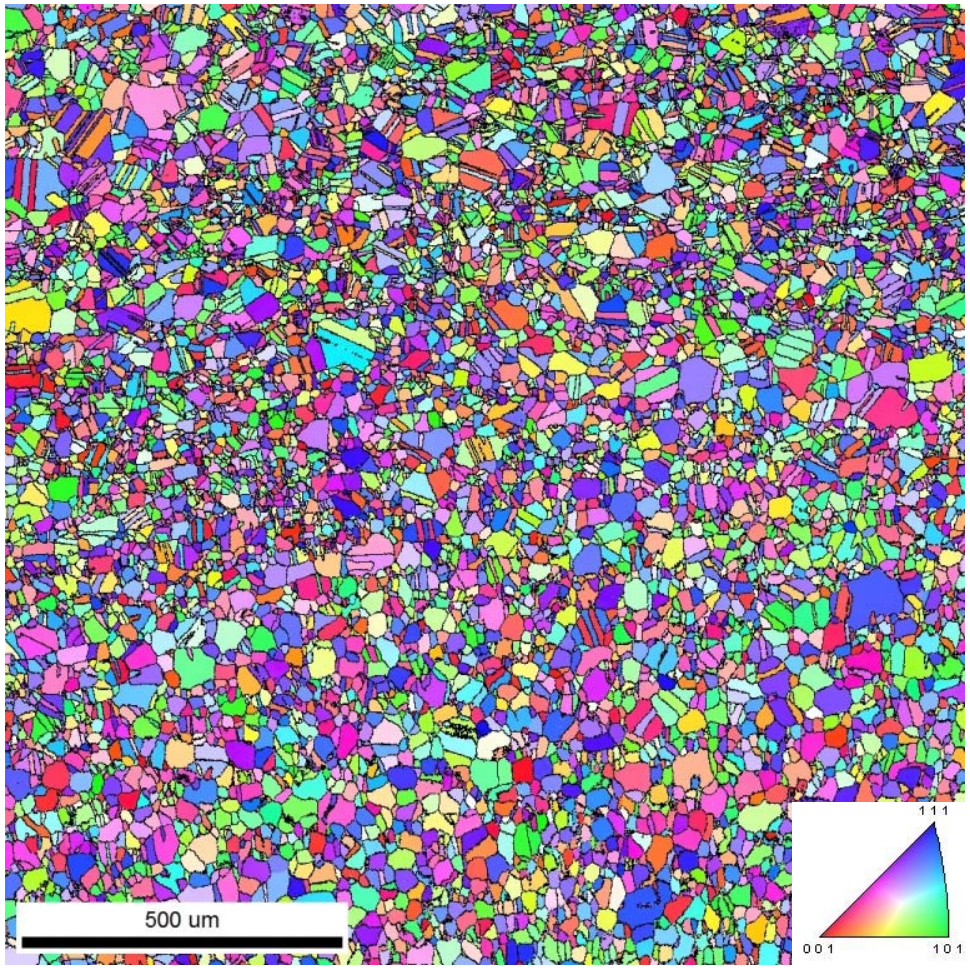




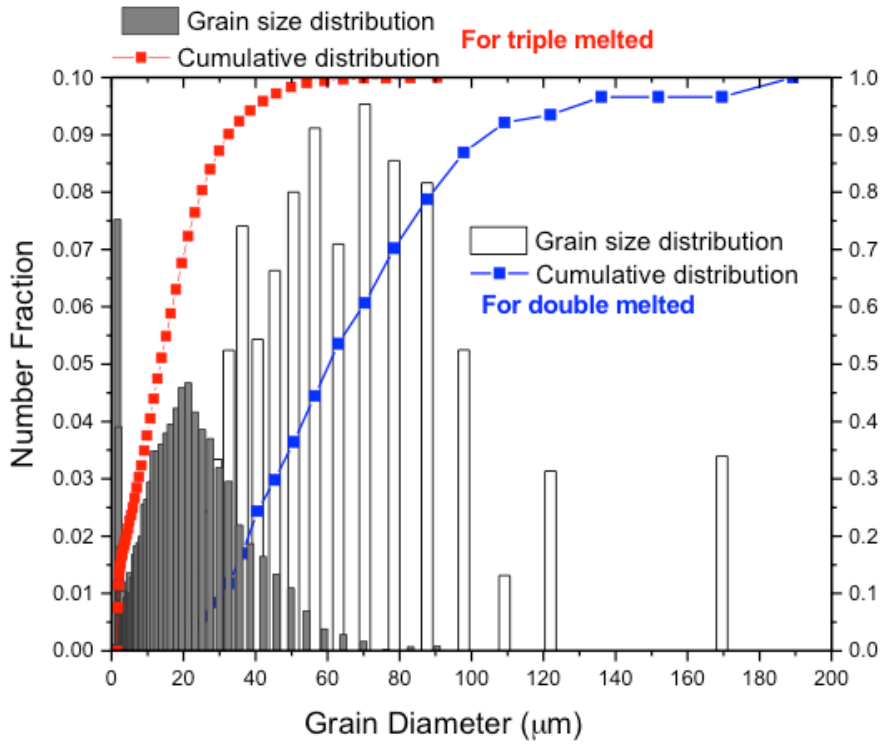
- Statistically significant difference between GE and ORNL data
- Large amount of time and energy expended in trying to find the source of differences (alignment, test procedure, heating procedure, HV, thermocouples etc.)

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

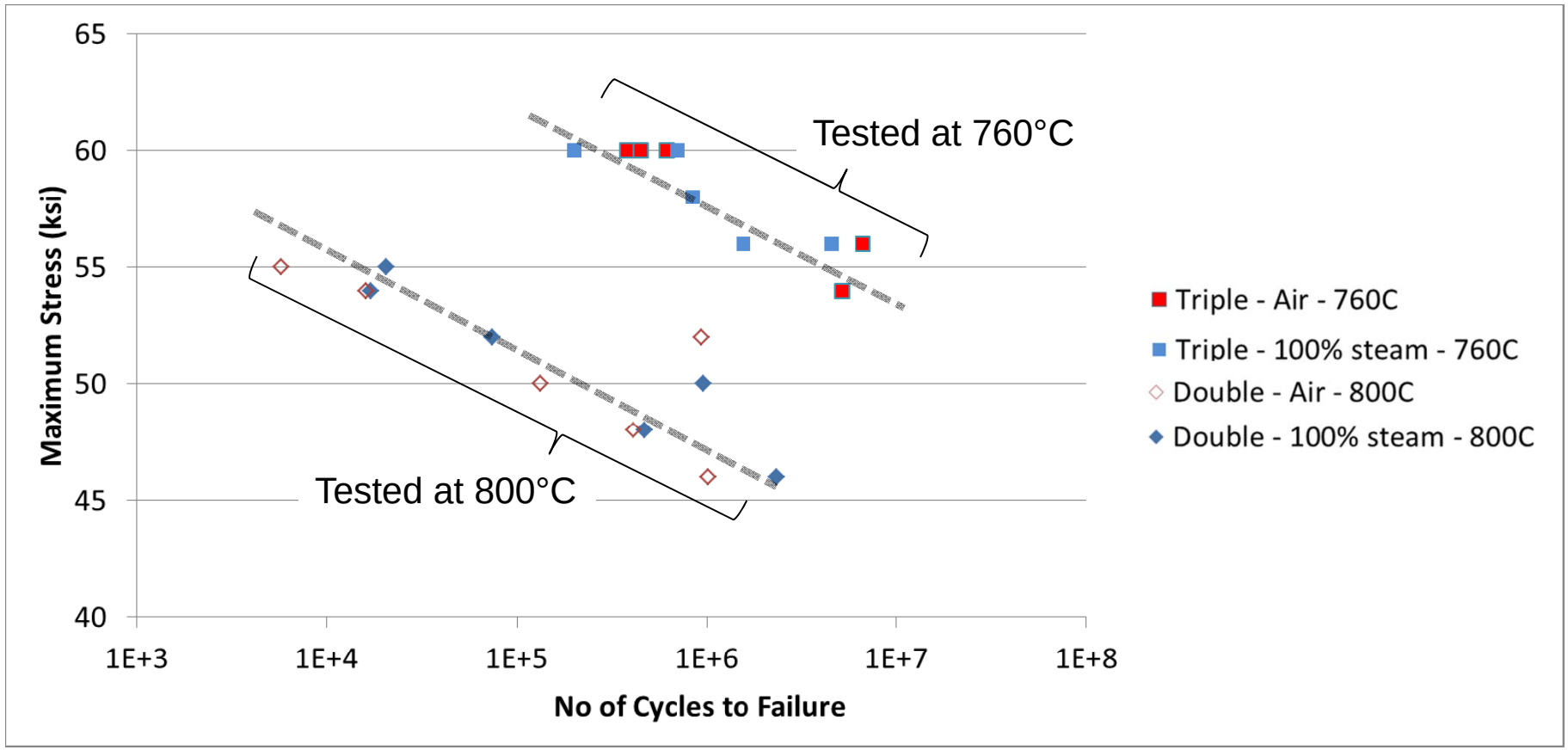
- Triple melted material is much finer and has a lower twin density than the double melted alloy 282



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

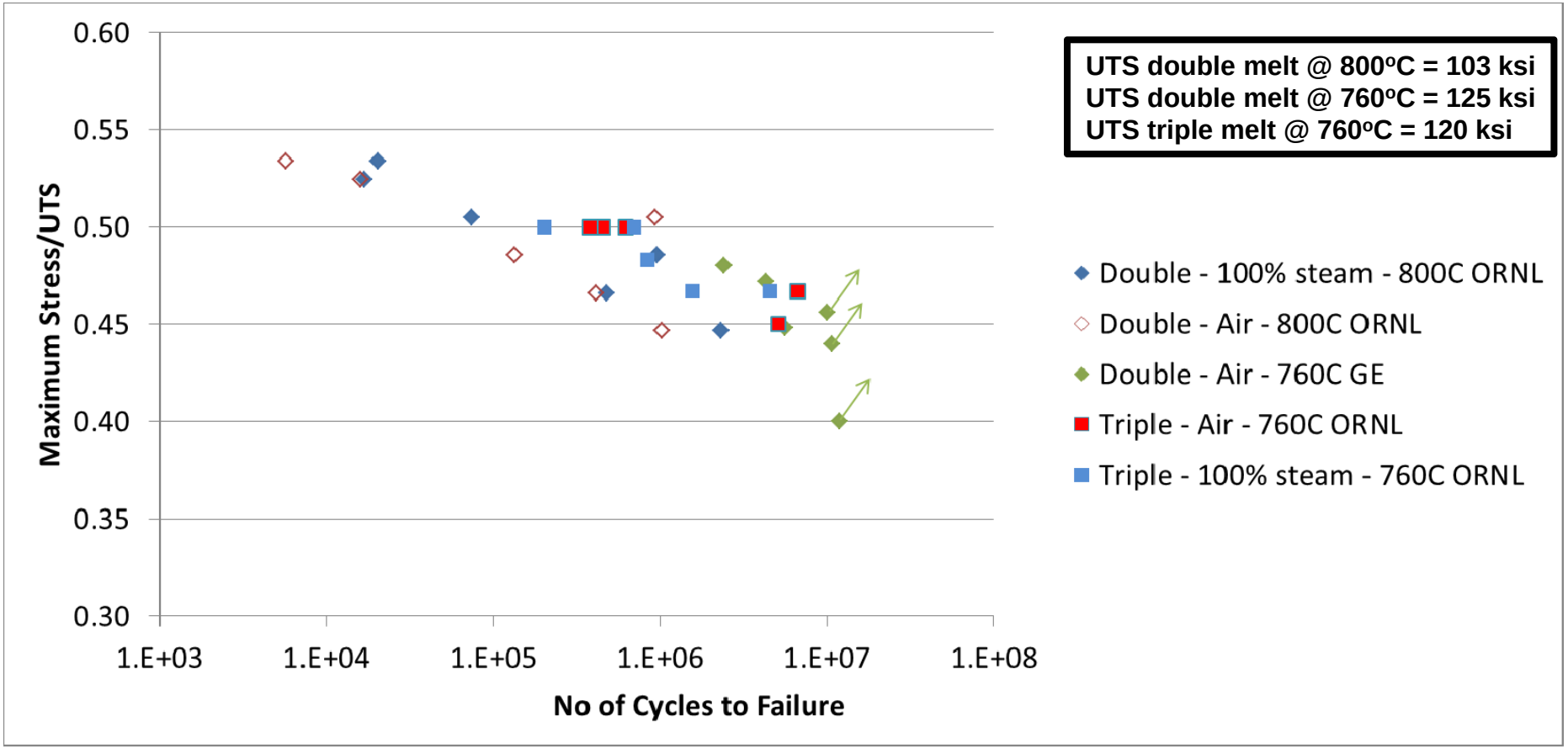


All R = -1 fatigue testing performed at ORNL (on double/triple melt materials)



- Improvement in fatigue behavior for the finer triple melt microstructure (at 760 ºC)
- No discernible effect of steam for either microstructure

There is *no significant effect* of microstructure and environment after this normalization



- Compare double and triple melted material fatigue data (normalized)

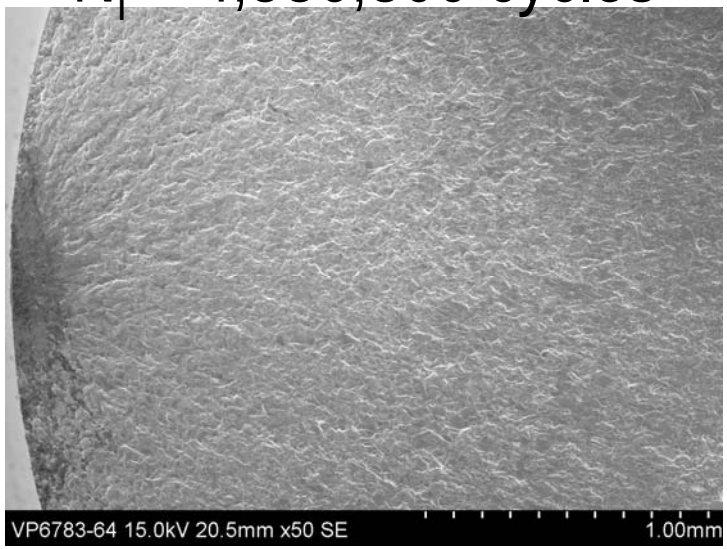
Summary and Conclusions – Fatigue of Wrought Haynes 282 Alloy

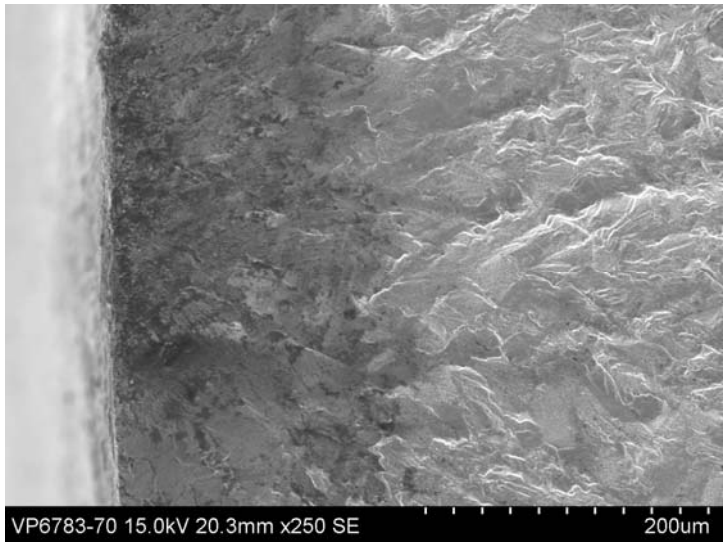
- One of a kind fatigue testing setup (100% steam and temperatures up to 900^{o}C) developed
- Steam fatigue testing on double-melted alloy 282 performed in air and 100% steam at 800^{o}C
- Failure lifetime variability related to failure location in double melt (surface versus subsurface)
- Triple melted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

And triple melt fracture surfaces – surface crack initiation dominates

100% steam @ 56 ksi

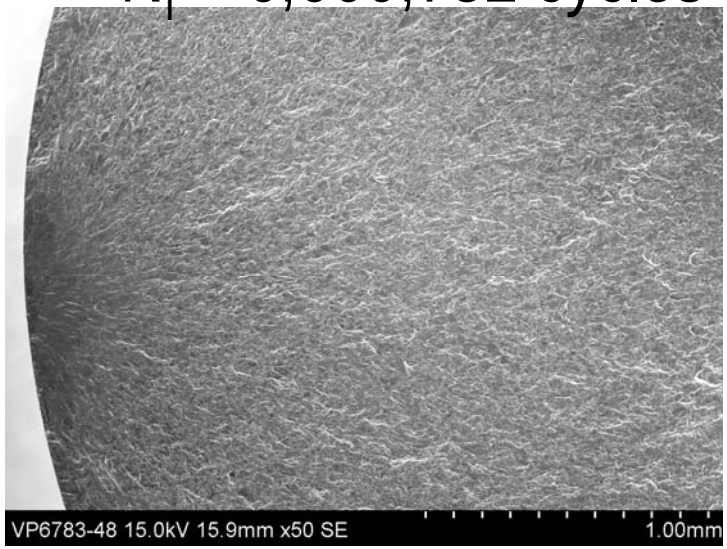
N_f = 4,536,800 cycles

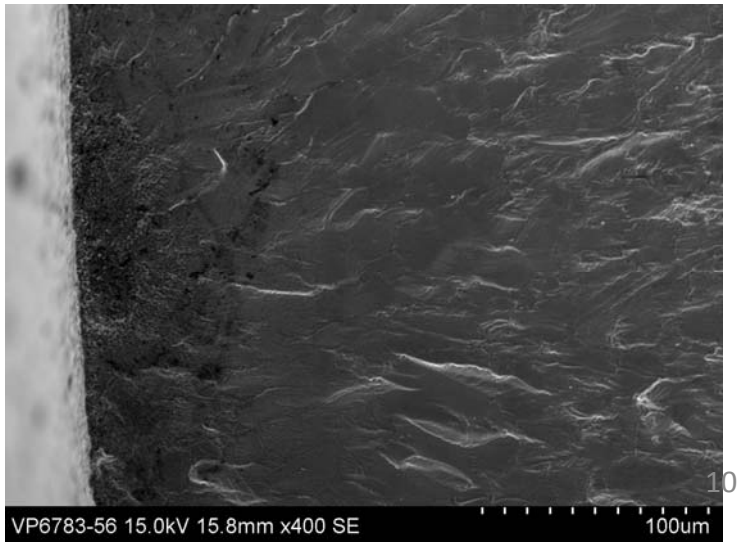




Air @ 56 ksi

N_f = 6,660,782 cycles





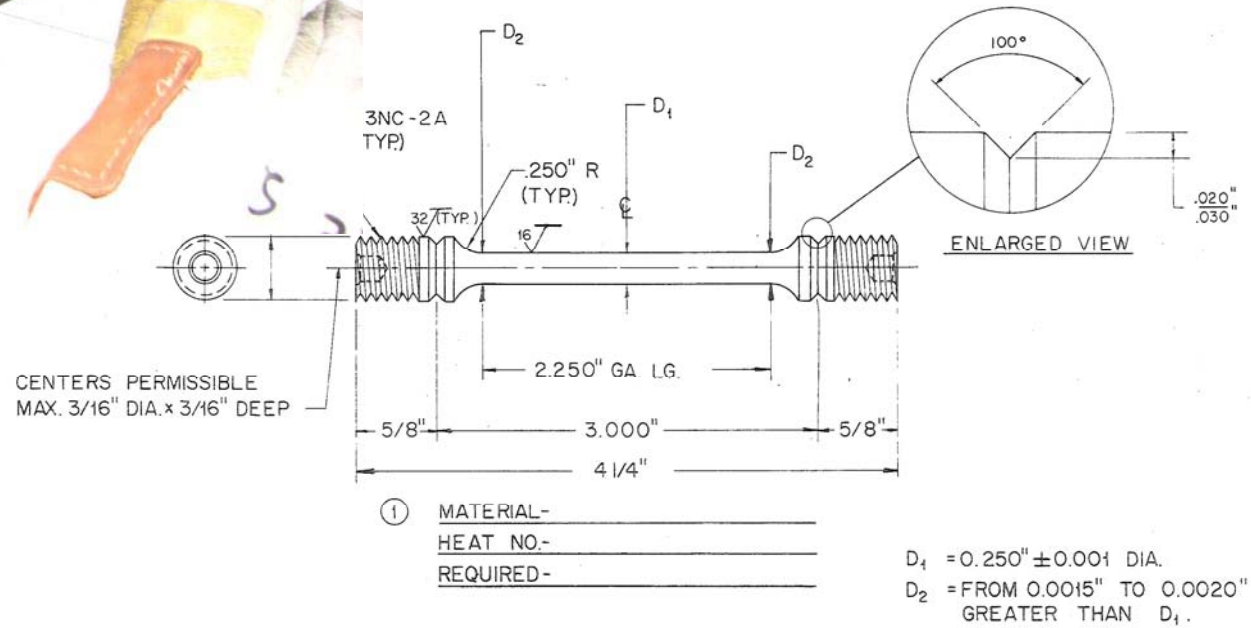
TASK 2 - WELDED CAST HR 282 ALLOY

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

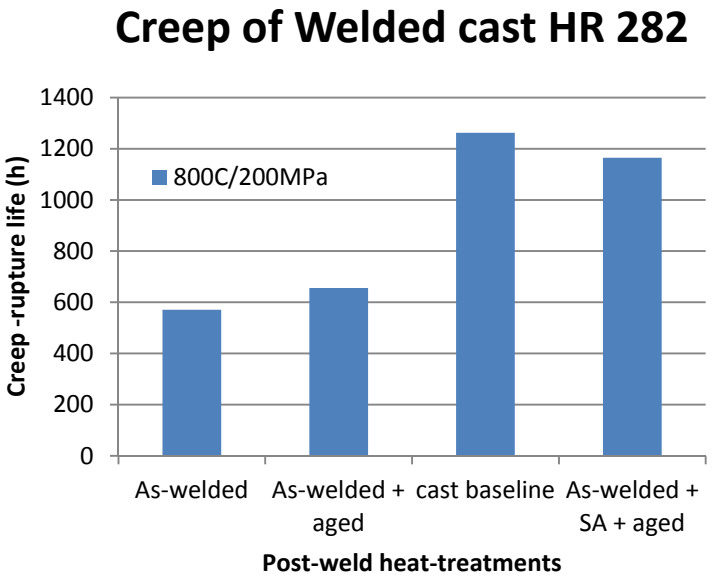
New work includes repeat creep-rupture testing of the fully heat treated welded cast Haynes 282 alloy

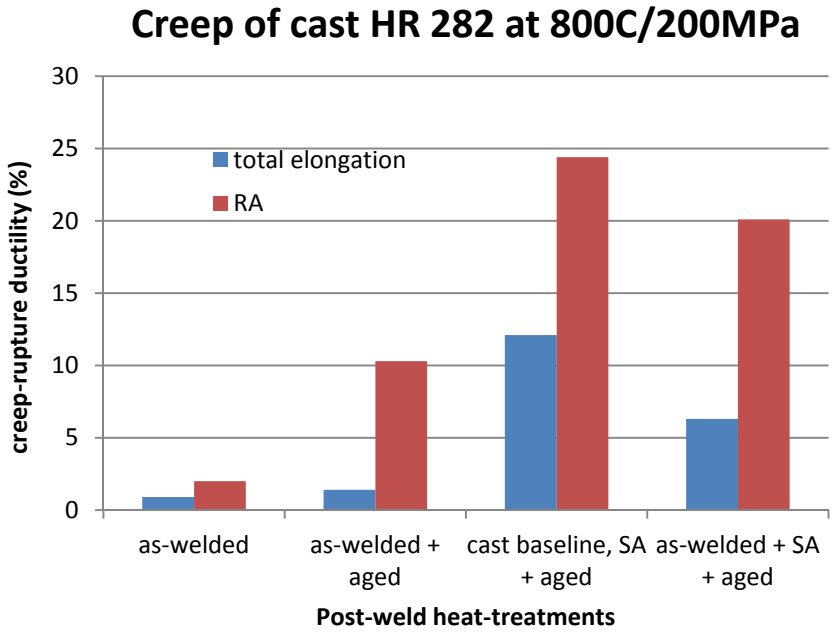
Testing of narrow-gap GTAWs supplied by GE

- 18 cross-weld specimens machined for stress-rupture

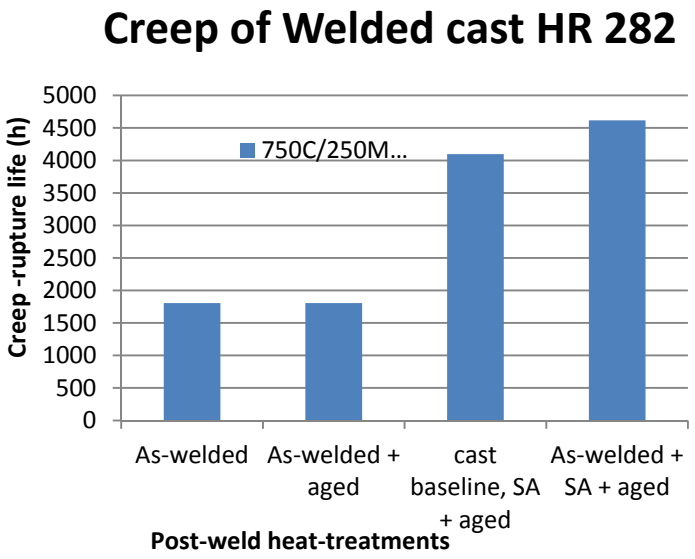


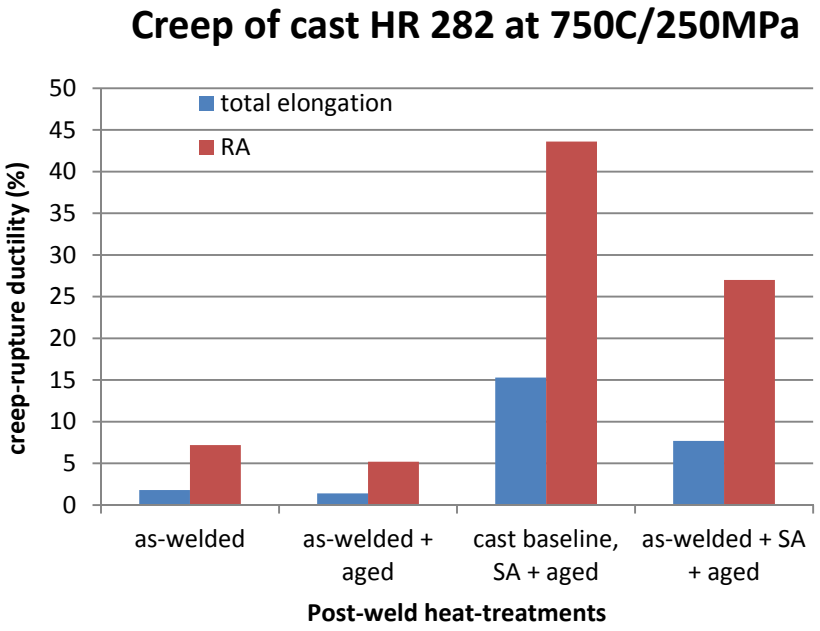
The Creep-Rupture Ductility Shows a Larger Effect of HT Than Does Rupture Life of Welded Cast HR 282 – 800°C/200MPa





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





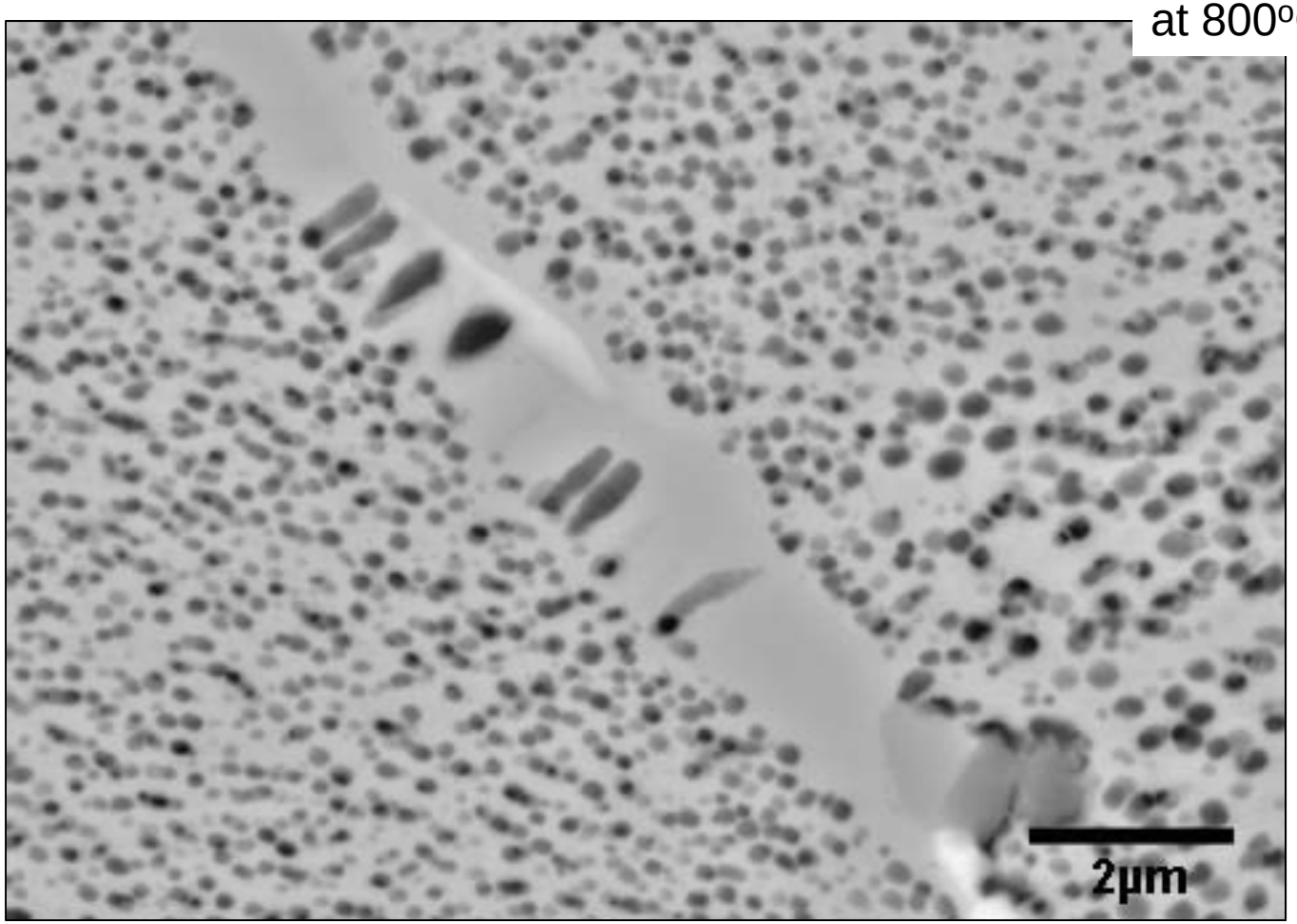
Repeat Creep-Rupture Testing of Fully-Heat Treated Cast and Welded Haynes 282 Alloy

- 800°C/200 MPa – 2207h, rupture (repeat)
  - 1175h, rupture (previous)
- 750°C/250 MPa – 5730h, rupture (repeat)
  - 4600h, rupture (previous)

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

TEM, Fusion Zone, fully heat-treated

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



Summary for Welded Haynes 282 Alloy

- Cast and homogenized Haynes 282 alloy is weldable, with good properties of weldment
- The full 2-step heat treatment is required to achieve good creep rupture life and ductility at 750-800^{o}C
- The effects of heat treatment on the welds of the cast alloy appear to depend on the details of the microstructure near the grain boundaries

NEW TASKS FY2016- LONG-TERM CREEP TESTING OF FORGED HAYNES 282 ALLOY, AND LARGE CASTING OF HAYNES 282 ALLOY

MAZIASZ, MOSER, (ORNL), SAHA (GE)

Large forging of HR 282 by GE

Large casting of half valve body of HR 282 by MetalTek and GE

ORNL began creep testing of specimens from GE large triple-melted forging of Haynes 282 alloy

- Previous GE creep testing showed lower creep resistance due to very fine grain size in the large forging relative to other creep data
- ORNL began long-term creep-rupture testing at ***1300F/32.5ksi, 1400F/15 ksi***, and ***1450F/8 ksi*** to obtain ***23,000 – 27,000h*** lifetimes proposed by GE.

Haynes 282 Steam Turbine partial valve casing

Haynes 282 valve casing after fettling, grinding and LPT inspections completion

- Worlds first large Haynes 282 casting with poured weight 17,000 lbs.
- Wall thicknesses 3.5 to 8 inches
- SDAS values in the range of 215µ to 275µ
- H282 Solutionizing & Double Age HT cycles carried out
- NDT inspections completed

ORNL has specimens from GE large casting of Haynes 282 alloy for creep-rupture testing

- ORNL has 8 specimens from discontinued creep rupture tests at 1300-1450^{o}F (706-787^{o}C) to continue testing until rupture
- ORNL has fresh GE specimens for long-term creep-rupture, LCF and for tensile testing
- ORNL has material from the large casting for microstructural evaluation

Summary

- GE forged triple-melt Haynes 282 alloy HCF testing is in progress at ORNL, and ORNL data no effects of steam at 760^{o}C
- Repeat creep testing finished on cast and welded HR 282 in the fully treated condition, and data are better than previous data
- ORNL is proceeding with long term creep tests on the largest heats of forged and cast Haynes 282 alloy in support of new efforts by DOE, EIO and EPRI on ComTest