A-USC Steam Cycle Turbine Materials

Phil Maziasz, Amit Shyam, Jeremy Moser, Chris Stephens, Kinga Unocic, and Ying Yang – ORNL

Deepak Saha, GE

Paul Jablonski - NETL-Albany

Bob Purgert, Roy Sheppard, and Nancy Flowen - EIO

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 %

<table>
<thead>
<tr>
<th></th>
<th>Ni</th>
<th>Cr</th>
<th>Co</th>
<th>Mo</th>
<th>Ti</th>
<th>Al</th>
<th>Fe</th>
<th>Mn</th>
<th>Si</th>
<th>C</th>
<th>B</th>
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<tbody>
<tr>
<td></td>
<td>57*</td>
<td>20</td>
<td>10</td>
<td>8.5</td>
<td>2.1</td>
<td>1.5</td>
<td>1.5*</td>
<td>0.3*</td>
<td>0.15*</td>
<td>0.06</td>
<td>0.005</td>
</tr>
</tbody>
</table>

* Maximum
** Nickel as balance
Comparison of ORNL fatigue data with GE data on double melted alloy 282

- ORNL testing at 800°C and 20 Hz sine wave
- GE testing at 760°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.

- **a) Air, N_f = 133,761 cycles**
- **b) Air, N_f = 936,659 cycles**
- **c) Steam, N_f = 957,736 cycles**
- **d) Steam, N_f = 73,798 cycles**
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 5°)

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

Average grain size (with twins) = $10.1 \pm 0.2 \mu m$
Average grain size (without twins) = $16.5 \pm 0.3 \mu m$

* GS calculated with number fractions
Summary and Conclusions

• One of a kind fatigue testing setup (100% steam and temperatures up to 900°C) developed
• Steam fatigue testing on double-melted alloy 282 performed in air and 100% steam at 800°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°C
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

Creep of Welded cast HR 282

Creep of cast HR 282 at 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
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

590h Creep tested at 800°C/200MPa 1250h
Fully heat treated cast HR 282 developed gamma prime denuded zones at GBs

Fusion Zone, fully heat-treated

Creep tested at 800°C/200MPa
Gamma Prime Structures of the Welded Cast HR 282 specimens are similar

Fusion Zone, as-welded

Fusion Zone, fully heat-treated

Creep tested at 800°C/200MPa

590h

1250h
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)
TEM/AEM identifies phases in welded cast HR 282, fully heat-treated and creep tested (800°C/200MPa)
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 HT establishes grain boundary precipitates and gamma prime
HIPed PM HR 282 - Creep-Rupture Testing is in Progress

- 800°C – creep at 200 MPa (46h)
- 800°C – creep at 200 MPa (77h)
- 800°C – creep of cast at 200 MPa (1250-2210h)
- 750°C – creep at 200 MPa (773h)
- 750°C – creep at 250 MPa (341h)
- 750°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°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°C/200MPa) shows heavy precipitation embrittlements 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