FEAA152-Evaluating Ni-Based Alloys for A-USC Component Manufacturing and Use

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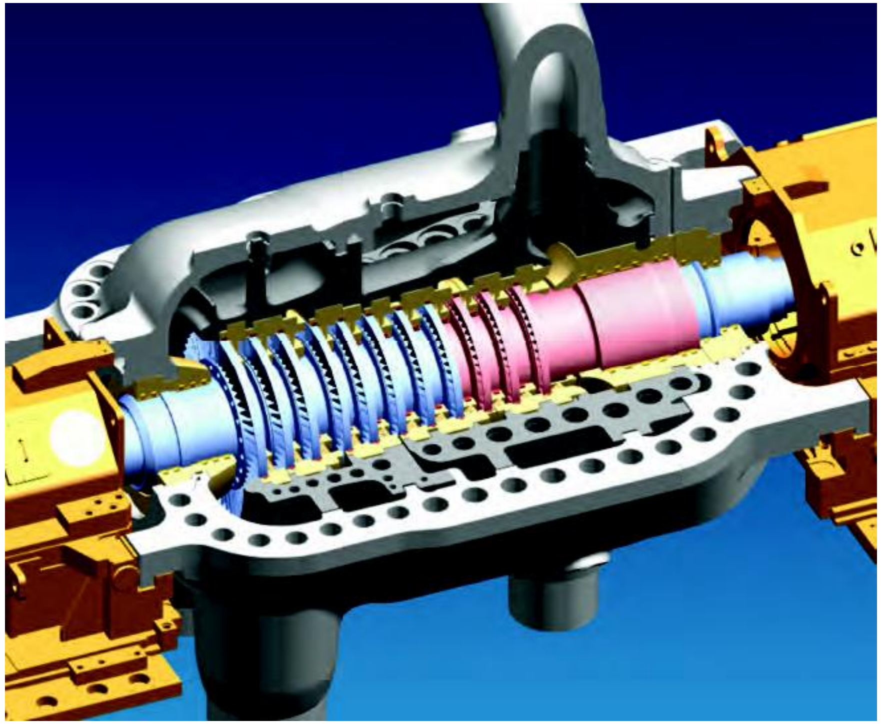
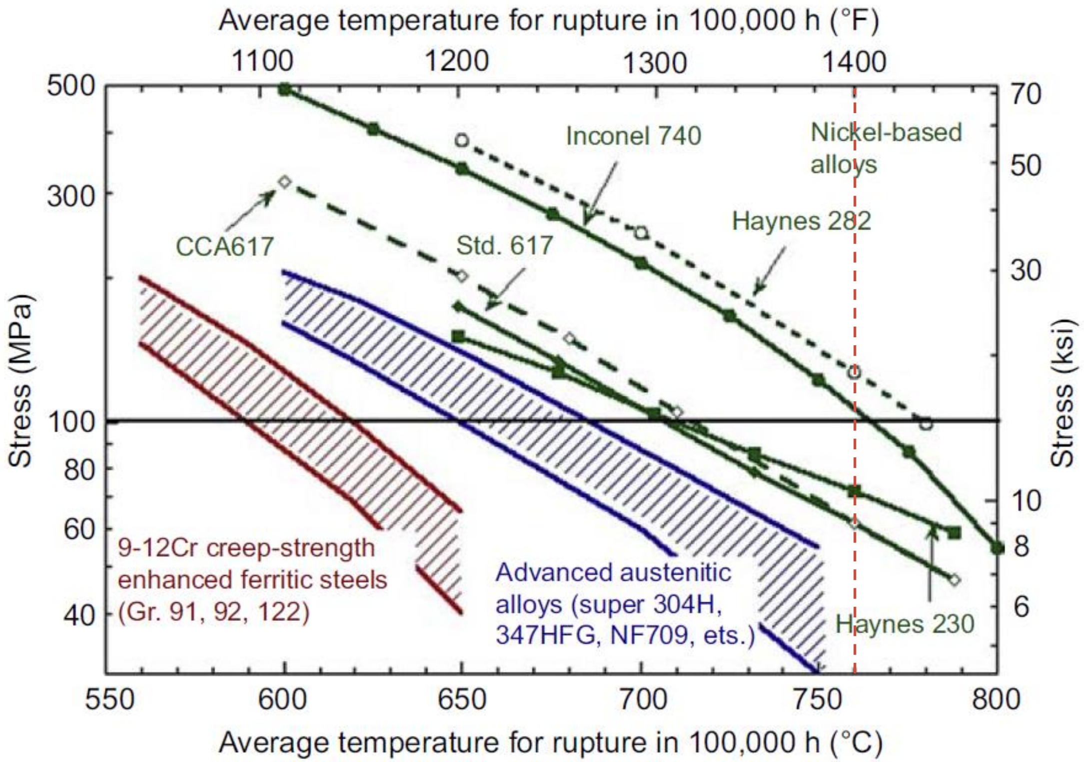
Background (1/3)



Advanced ultrasupercritical steam turbine
Schwant et al 2013



100kh creep rupture strength as a function of temperature
Shingledecker et al 2013

- Advanced Ultra-Supercritical (A-USC) power plants require steam conditions up to 760°C (1400°F)/35 MPa (5 ksi), mandating the use of Ni-based alloys for the highest temperatures and pressures
- Two precipitation-strengthening Ni-based alloys, i.e., Haynes® 282 ® and Inconel® 740H®, are considered as leading candidate materials for A-USC applications

Background (2/3)

- Ni-based alloys account for an important portfolio of the Fossil Energy materials program

2001-2015

Boiler materials for ultra supercritical coal power plants

2009-2015

Materials for advanced ultrasupercritical steam turbines

2015-2018

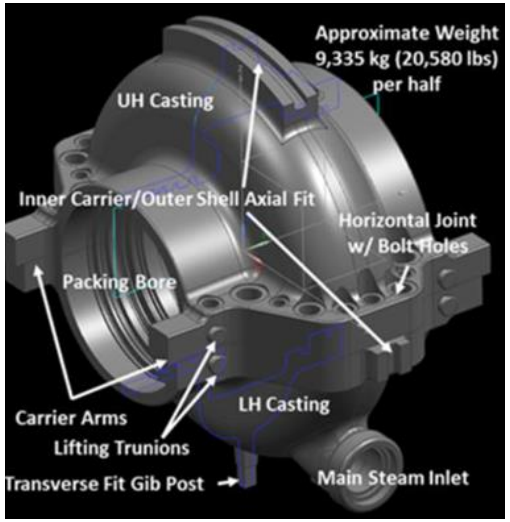
ComTest Phase 1

2019-

ComTest Phase 2

IN740H pipe
15" OD, 8" ID, 34.5 feet long
Viswanathan et al 2009

Haynes 282 triple-melt forged disk
Purgert et al 2015



Planned 10-ton Haynes 282 nozzle carrier casting
Purgert and Hack 2019

Background (3/3)

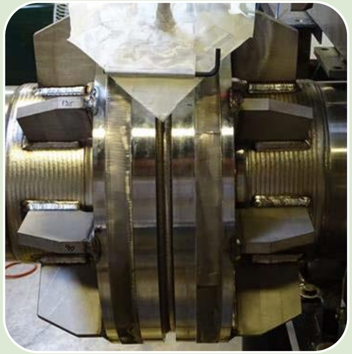
- Characterization of Ni-based alloys, especially from large-scale components, provides
  - **Data needed for materials qualification**
  - **Insights into potential manufacturability issues**

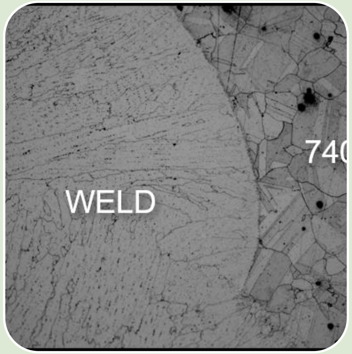
Sand casting 7.7-ton Haynes 282. Letters indicating sampling locations

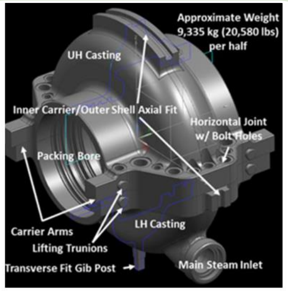
Purgert et al 2015

Objective: This research provides a critical evaluation of advanced Ni-based alloys supporting the manufacturing and use of components under advanced ultra-supercritical (A-USC) steam conditions

Materials Evaluation Matrix



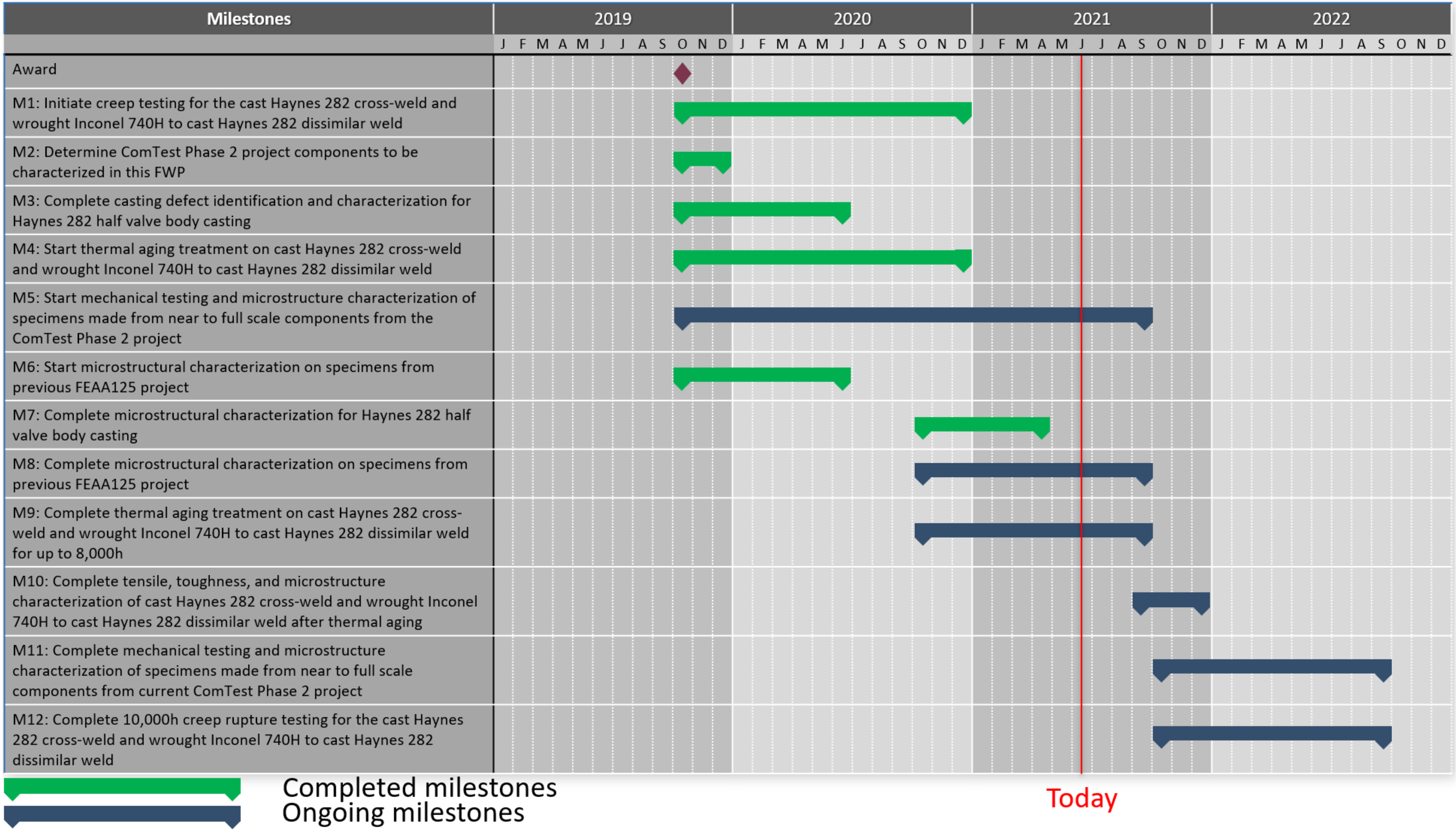




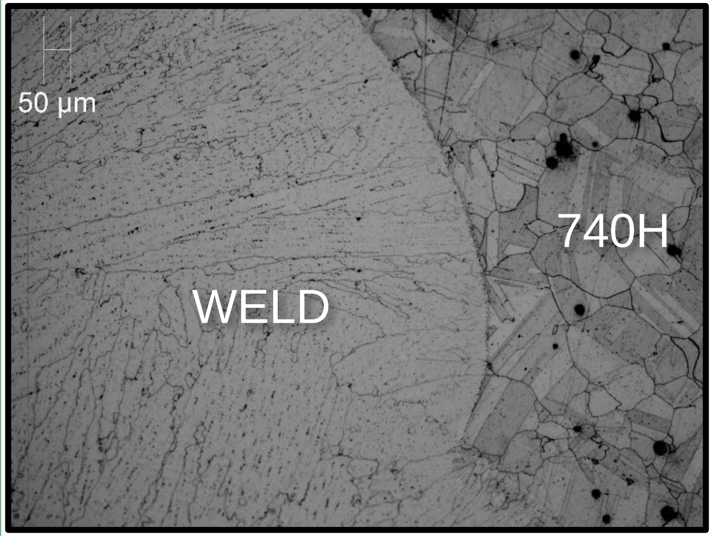
Planned 10-ton Haynes 282 nozzle carrier casting

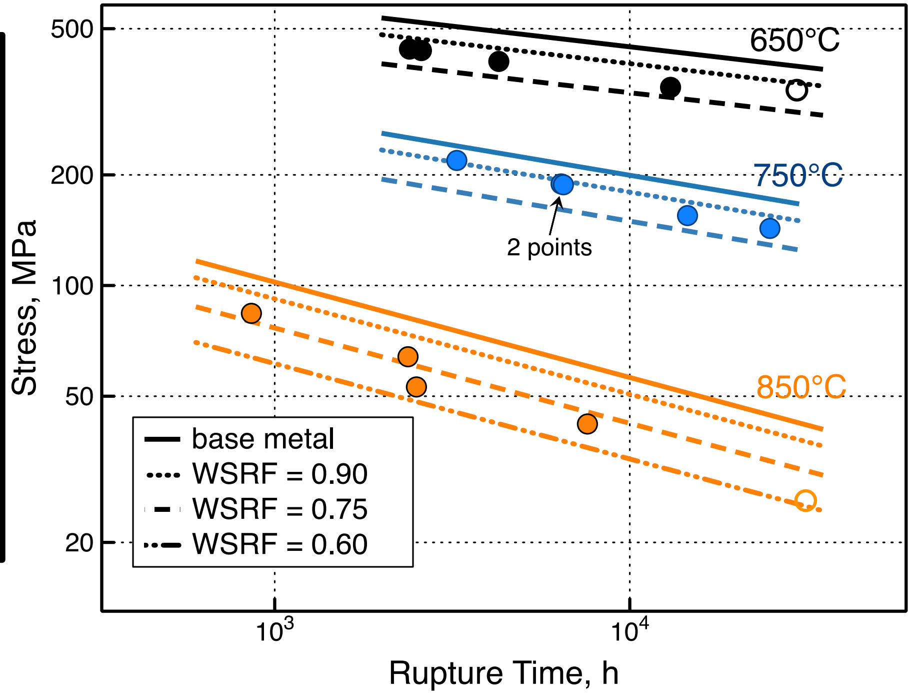
Haynes 282 sand casting	Haynes 282 triple-melt forged disk	Cast Haynes 282 GTAW	DMW between cast Haynes 282 and Inconel 740H	Inconel 740H SMAW with alloy 263 filler metal	ComTest Phase 2 materials

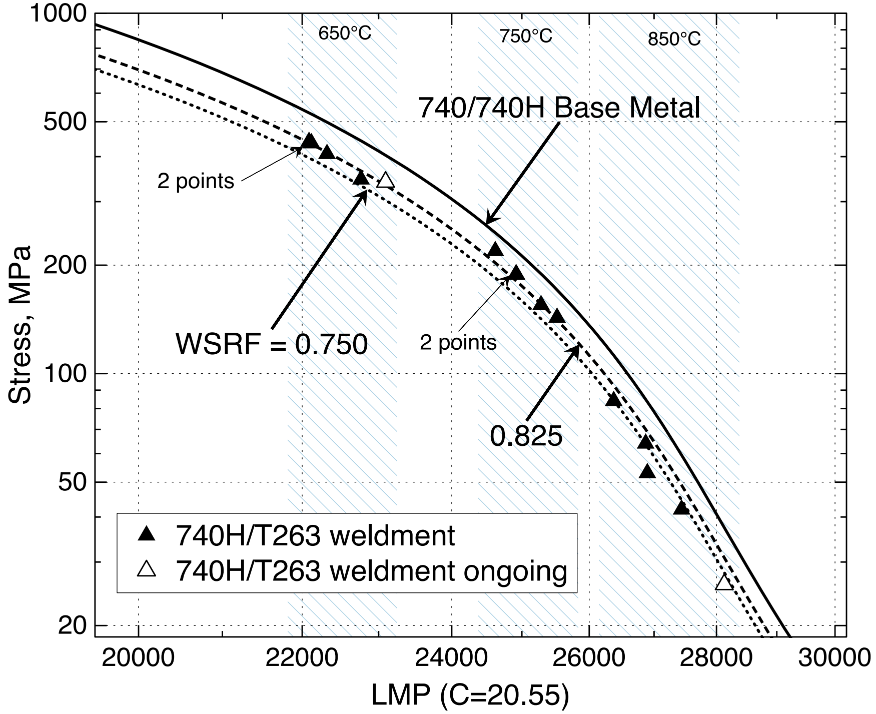
Milestone Status



Highlights: cross-weld creep testing of Inconel 740H shield metal arc welding made with alloy 263 filler metal (in collaboration with Special Metals) showed fairly good strength retention at 650 and 750 °C





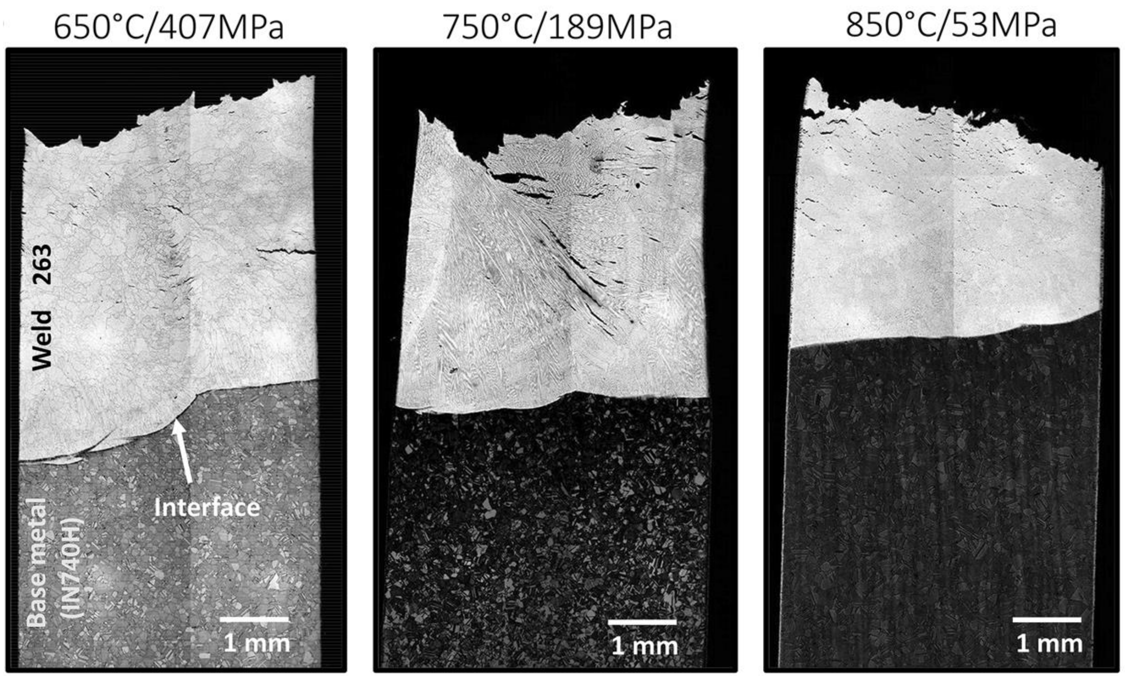


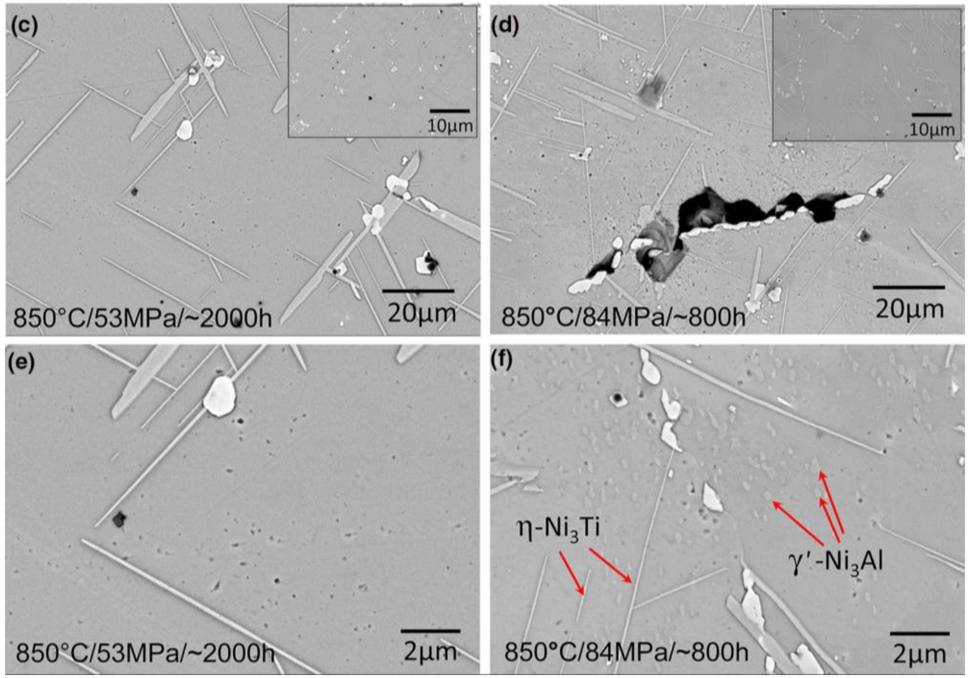
Solid symbols for finished tests and open symbols for ongoing tests as of 03/31/21

Cross-weld creep testing showed reduction in the creep strength of the weld with weld strength reduction factors (WSRFs) of approximately **0.825 at 650 and 750°C, but < 0.75 at 850°C**

Microstructural Evaluation of the Weld after Creep Testing

- All creep failures occurred within the weld region, with intergranular failure and cracks propagated along grain boundaries
- Inconel 740 had better microstructural stability than alloy 263 at testing temperatures
- Evident microstructural changes were observed in alloy 263 tested at 850°C, with a strong Widmanstätten pattern of η-Ni_3Ti phase at the expense of Mo, Ti carbides and γ’ phase (Ni_3Al,Ti).

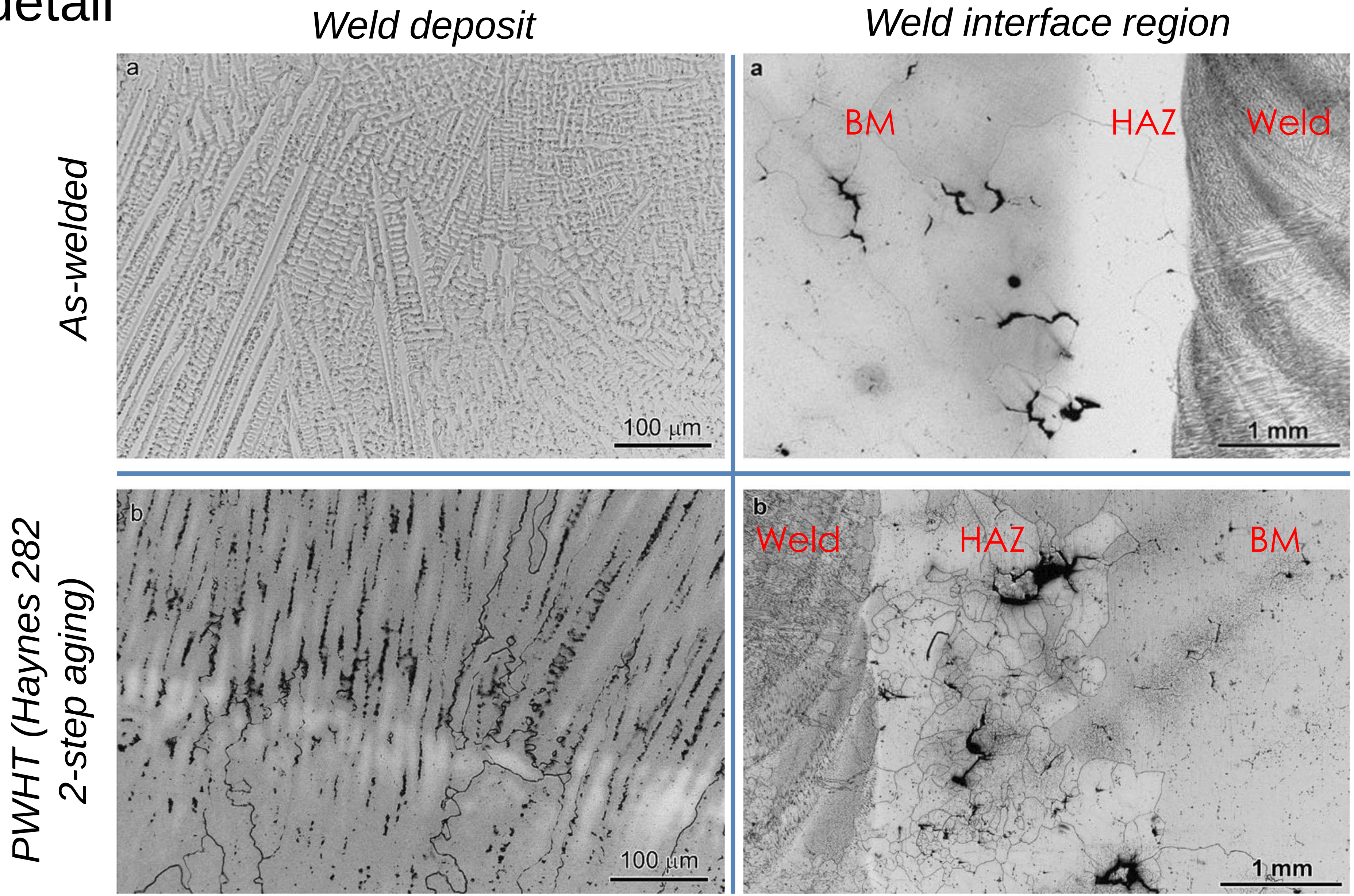




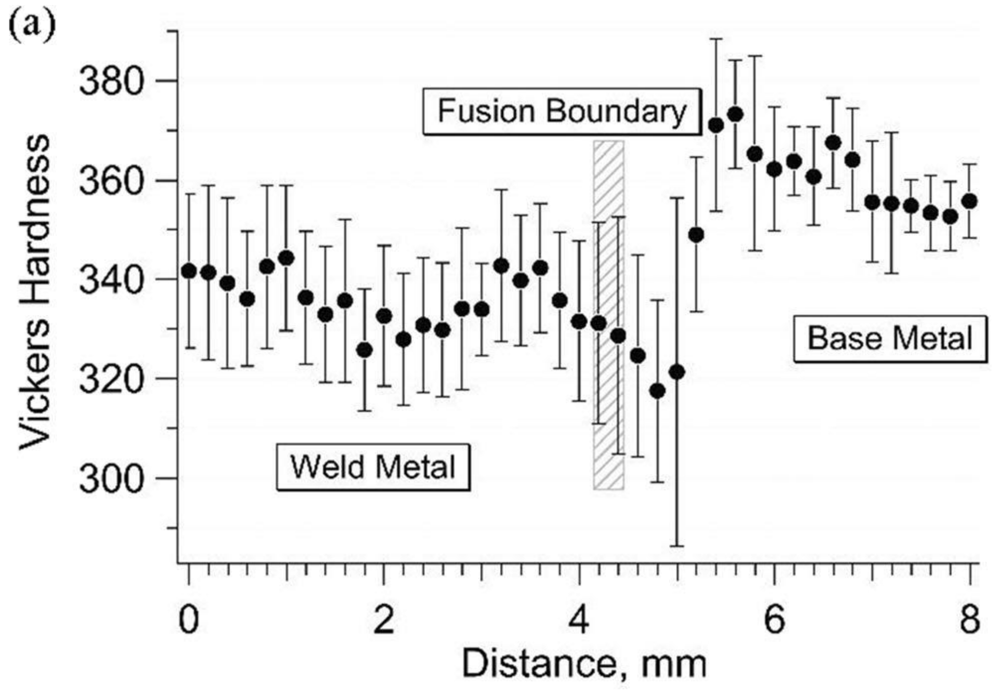
K.A. Unocic, X. Chen, P.F. Tortorelli, Microstructural Evaluation of Welded Nickel-Based Superalloy Inconel 740H After Creep Testing. *JOM* **72,** 1811–1821 (2020).

Highlights: cast Haynes 282 gas tungsten arc welding was characterized in detail

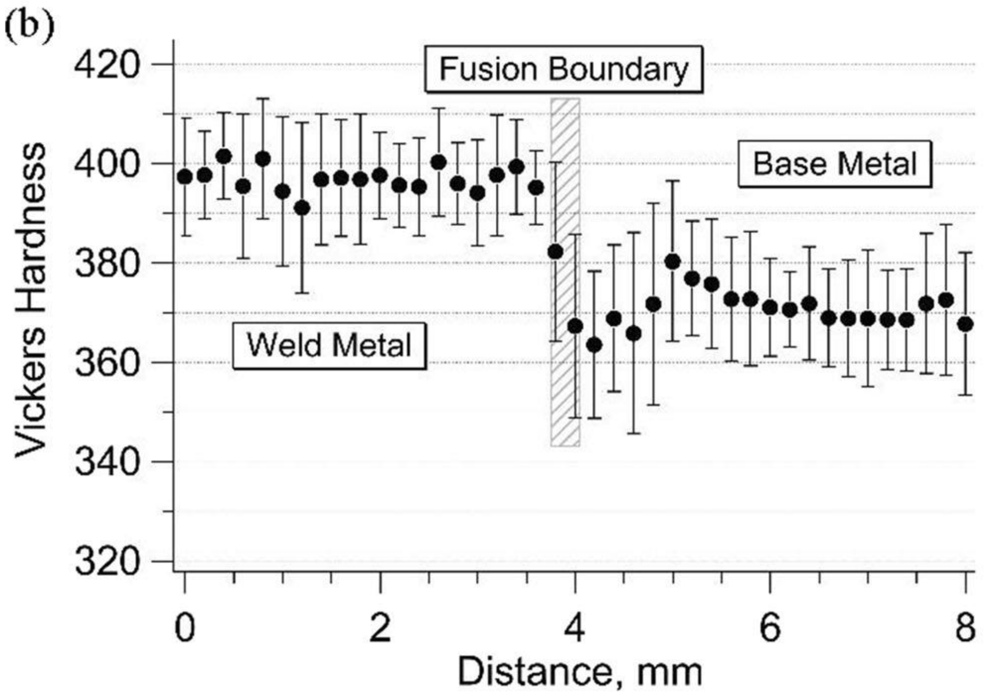
- The weld deposit contained no visible indication of physical defects
- Cracks were observed near or within the HAZ
  - Cracks from the base metal?
  - Strain-age cracking?
  - Heat-affected zone cracking?
- Recrystallization near weld HAZ



Beneficial effects of post weld heat treatment were identified



As-welded

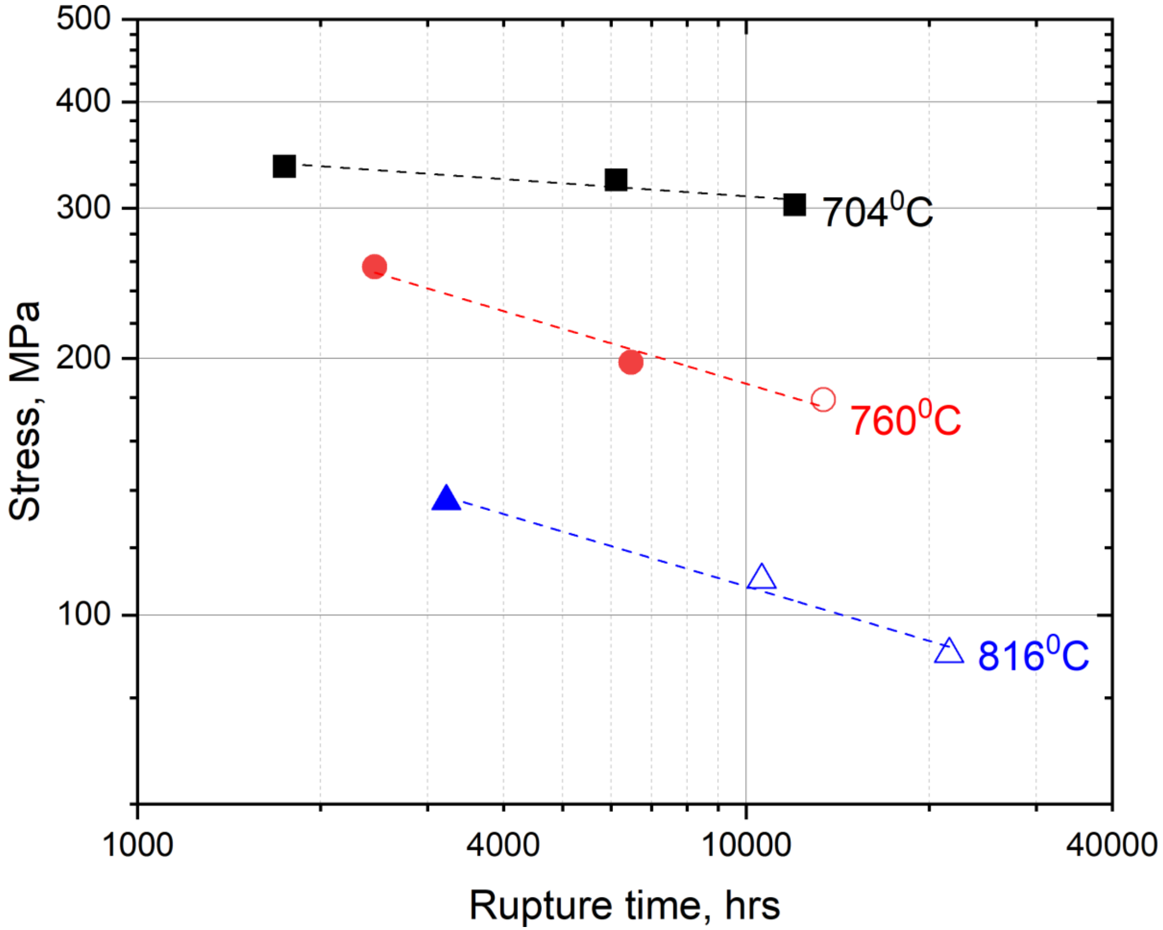


PWHT (Haynes 282 2-step aging)

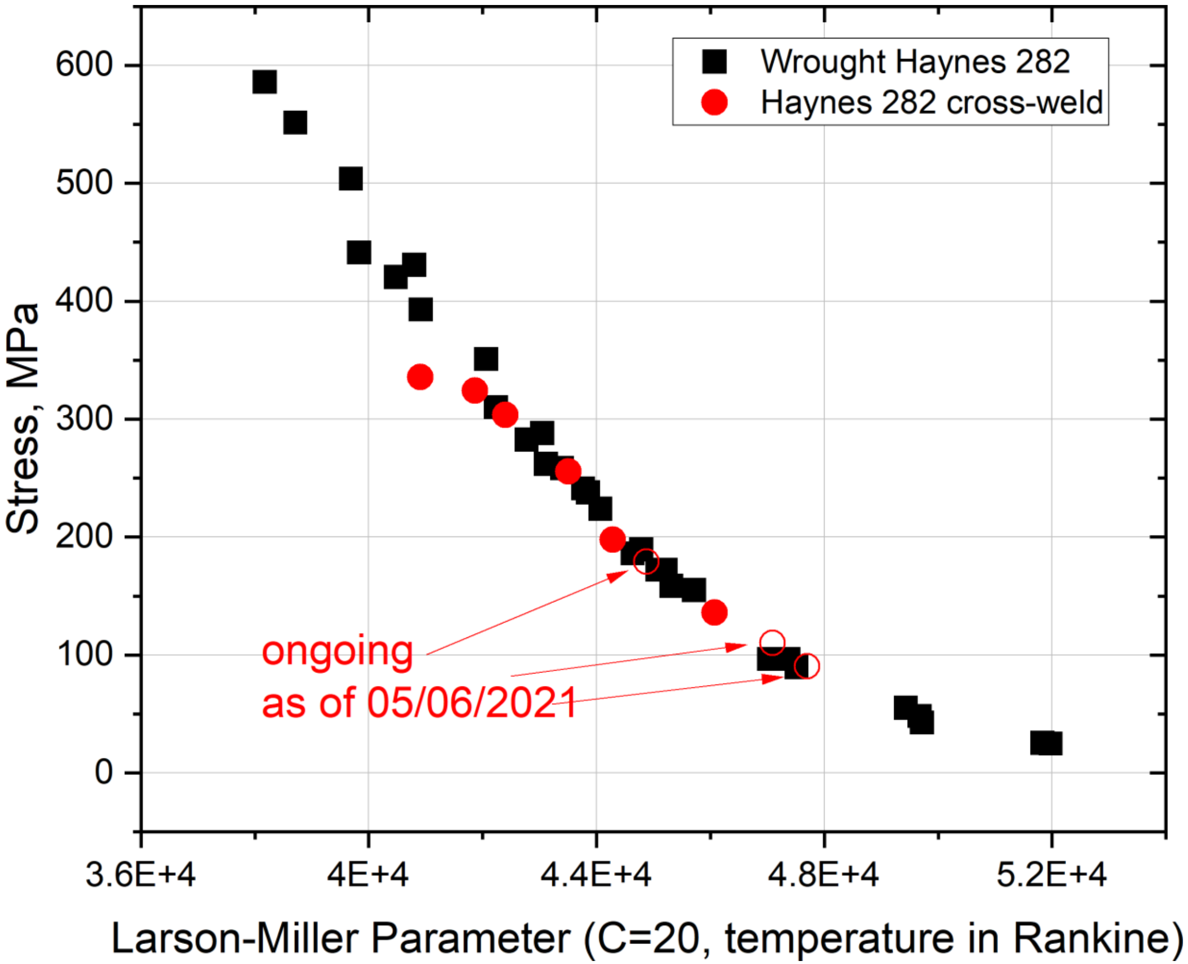
- Hardness gradients in the heat affected zone were significantly reduced by PWHT
- Higher hardness in the weld deposit after PWHT due to higher Al and lower C contents
- No clear effect of HAZ recrystallization on the hardness

M. Santella, X. Chen, P. Maziasz, et al. Properties of a thick-section narrow-gap gas tungsten arc weld of cast Haynes 282. Weld World 65, 961–971 (2021)

Cross-weld creep results indicated similar Larson-Miller Parameter without weld strength reduction compared with the wrought



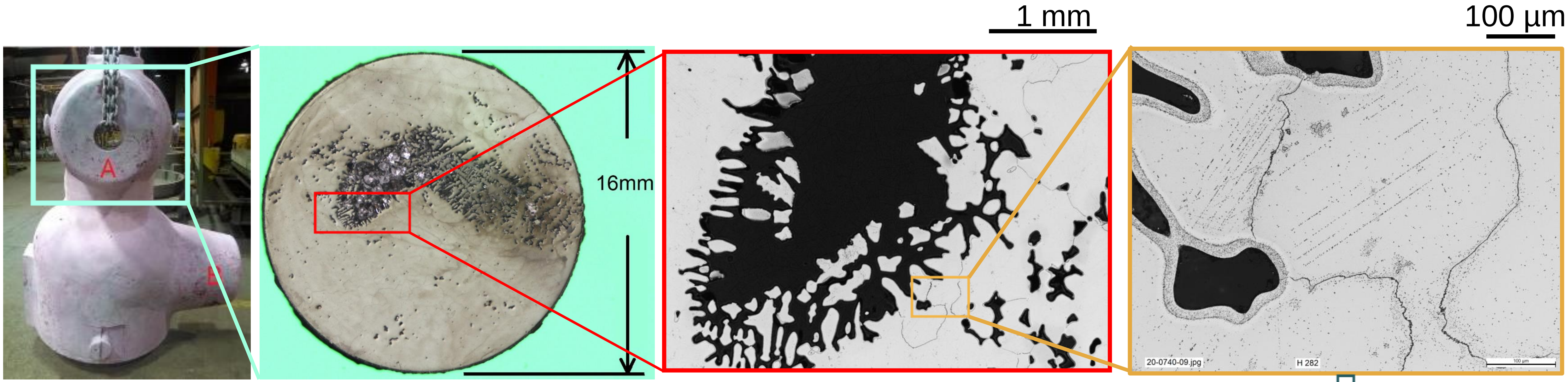
Solid symbols for finished tests and open symbols for ongoing tests as of 05/06/2021

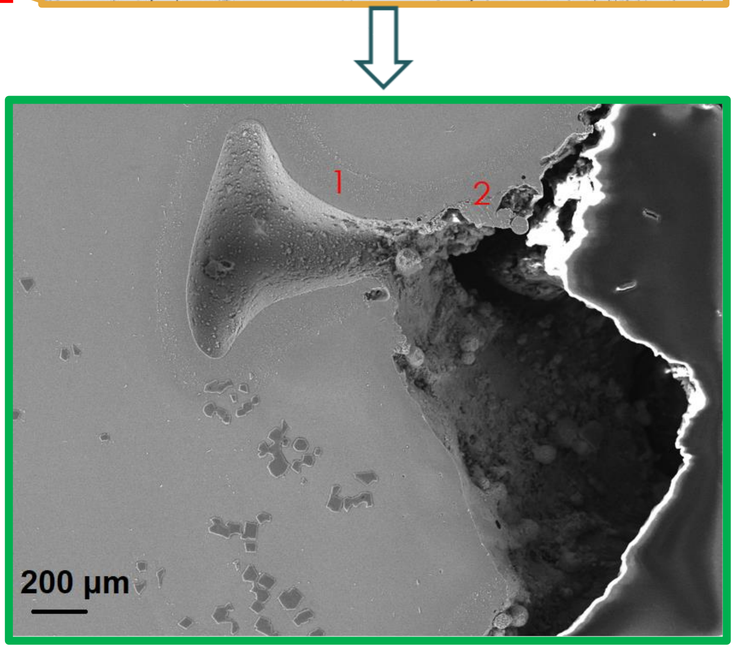


[Viswanathan, R. et al, "Steam Turbine Materials for Ultrasupercritical Coal Power Plants," Final technical report, 2009, doi:10.2172/1081317]

- Except for one specimen, all failure locations were within the base metal

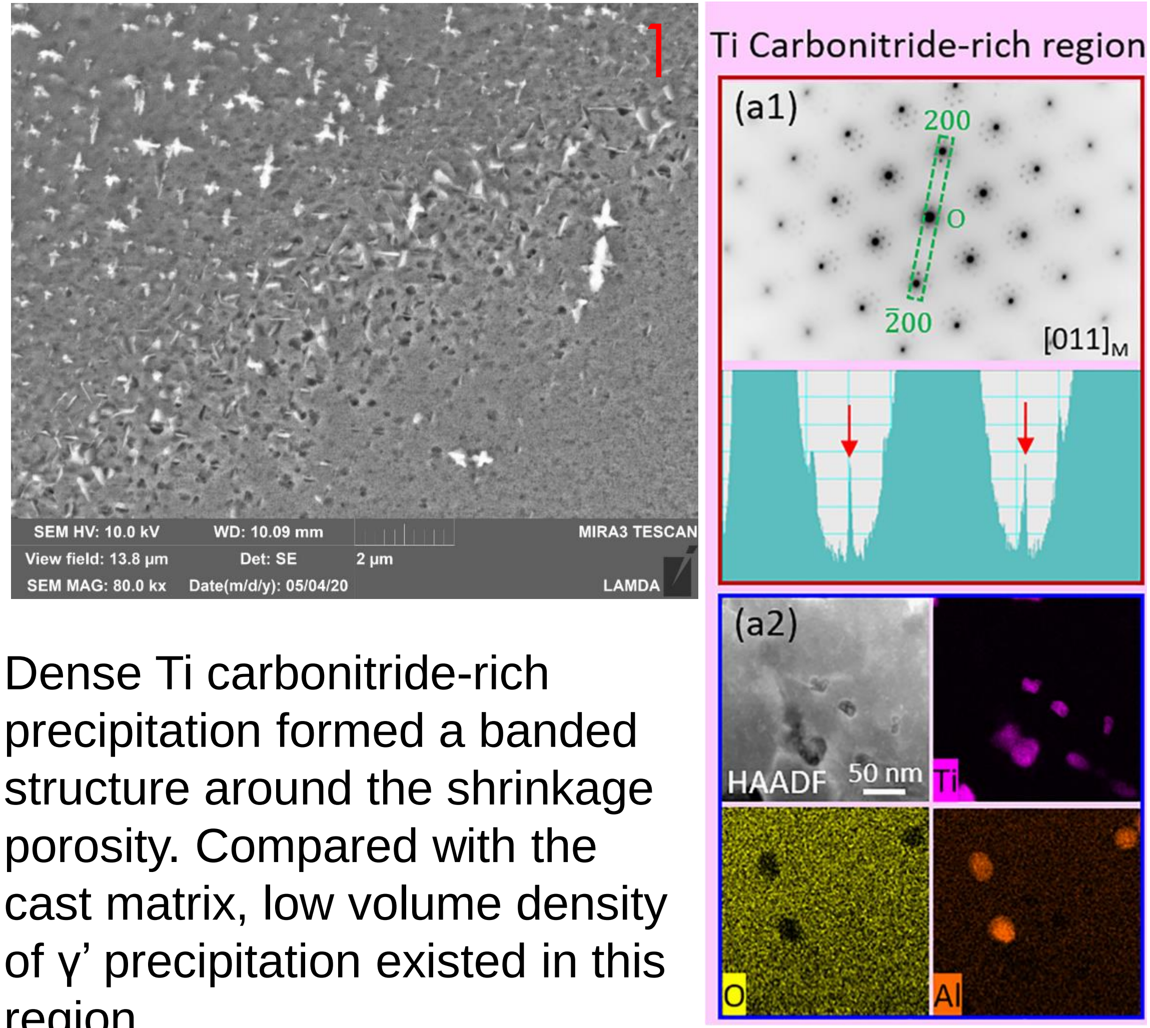
Highlights: precipitation near cast Haynes 282 shrinkage defects characterized



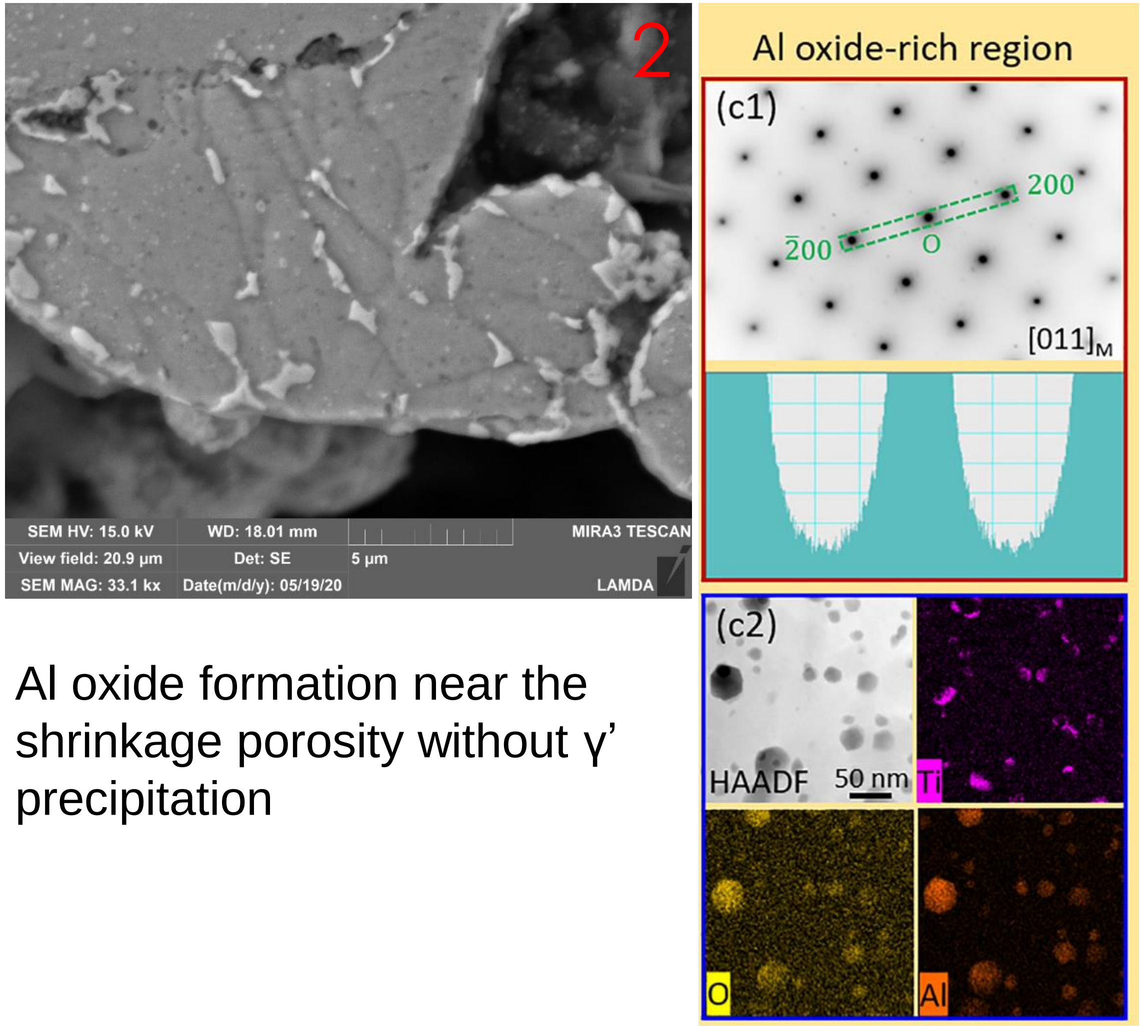


- Two unique regions were identified near a casting shrinkage defect
  - 1: precipitation rich banded region
  - 2: oxidized region

Two unique microstructural features were identified



Dense Ti carbonitride-rich precipitation formed a banded structure around the shrinkage porosity. Compared with the cast matrix, low volume density of γ’ precipitation existed in this region

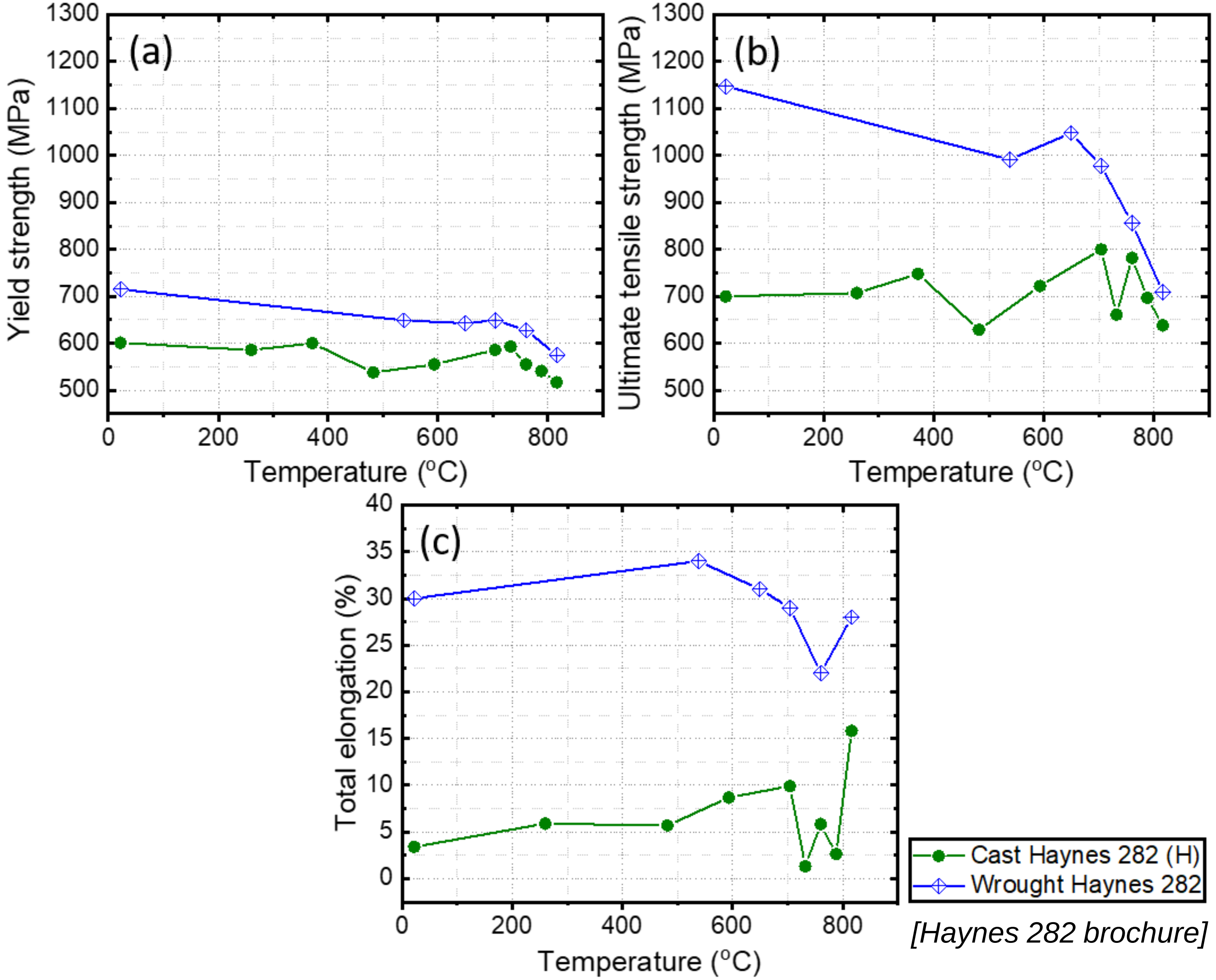


Al oxide formation near the shrinkage porosity without γ’ precipitation

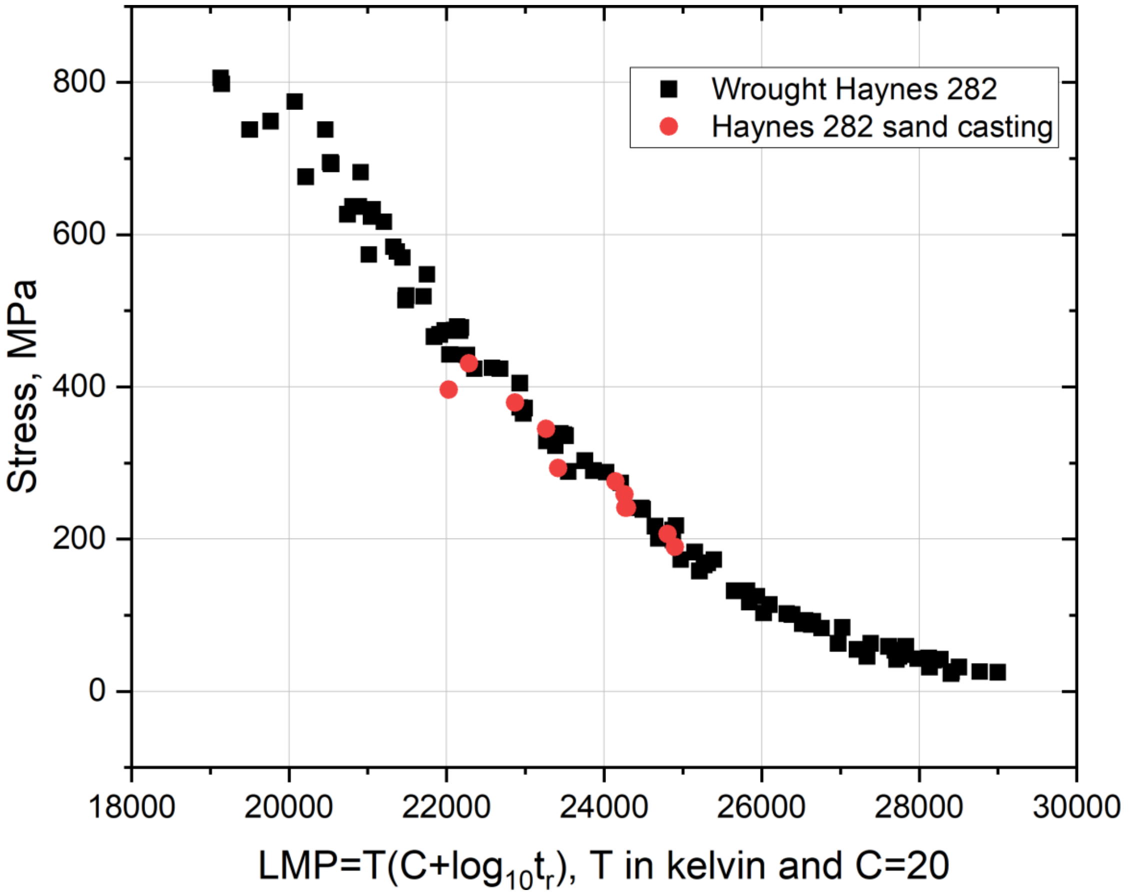
L. Wang, K. Unocic, P. Tortorelli, M. Santella, X. Chen, Precipitation behavior near shrinkage porosity in a large sand casting of Haynes 282 alloy, ***Materialia*** *15, 101035 (2021).*

Highlights: tensile and creep properties of the large Haynes 282 sand casting were determined

- **Lower tensile strength and ductility** in comparison with the wrought
- **Similar creep behaviors** between the two



[Haynes 282 brochure]

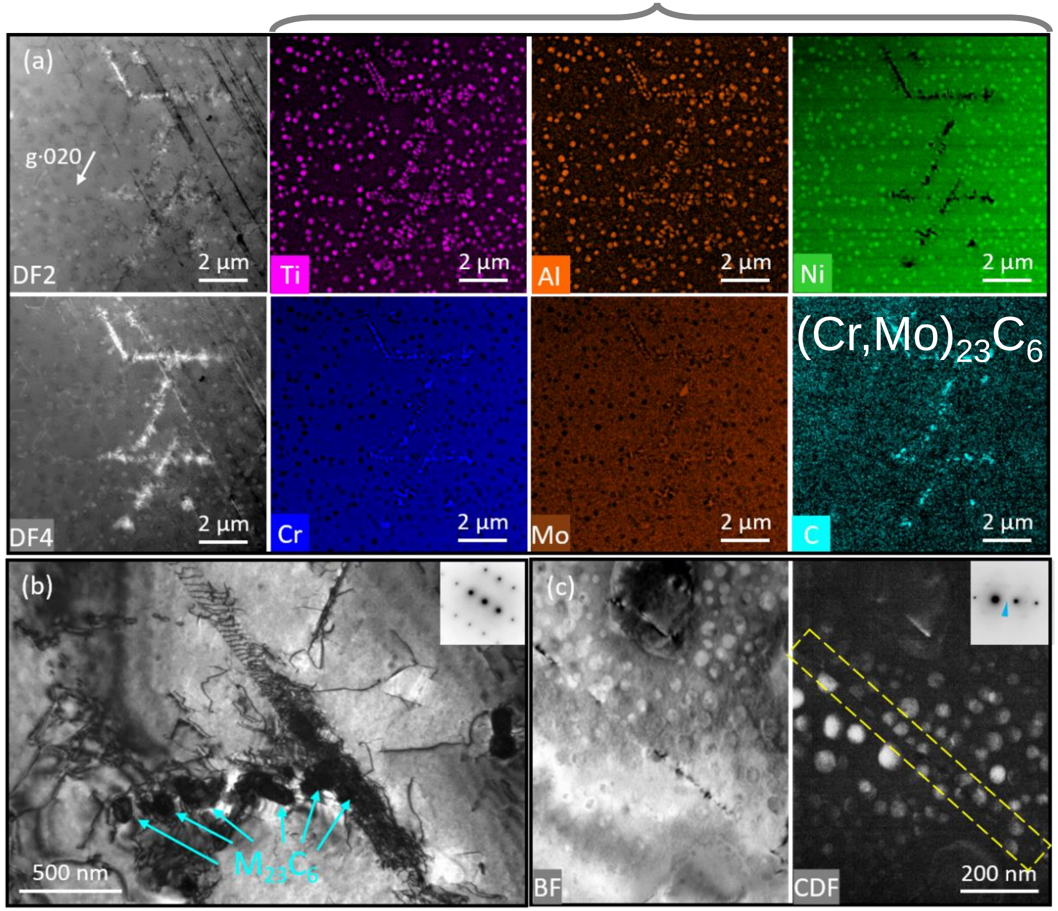


[Pint et al., ORNL/TM-2020/1548]

X. Chen, P. Maziasz, P. Tortorelli, et al., Characterization of Ni-based Alloys for Advanced Ultra-supercritical Power Plants, Proceedings of Joint EPRI-123HiMAT International Conference on Advances in High Temperature Materials, 2019

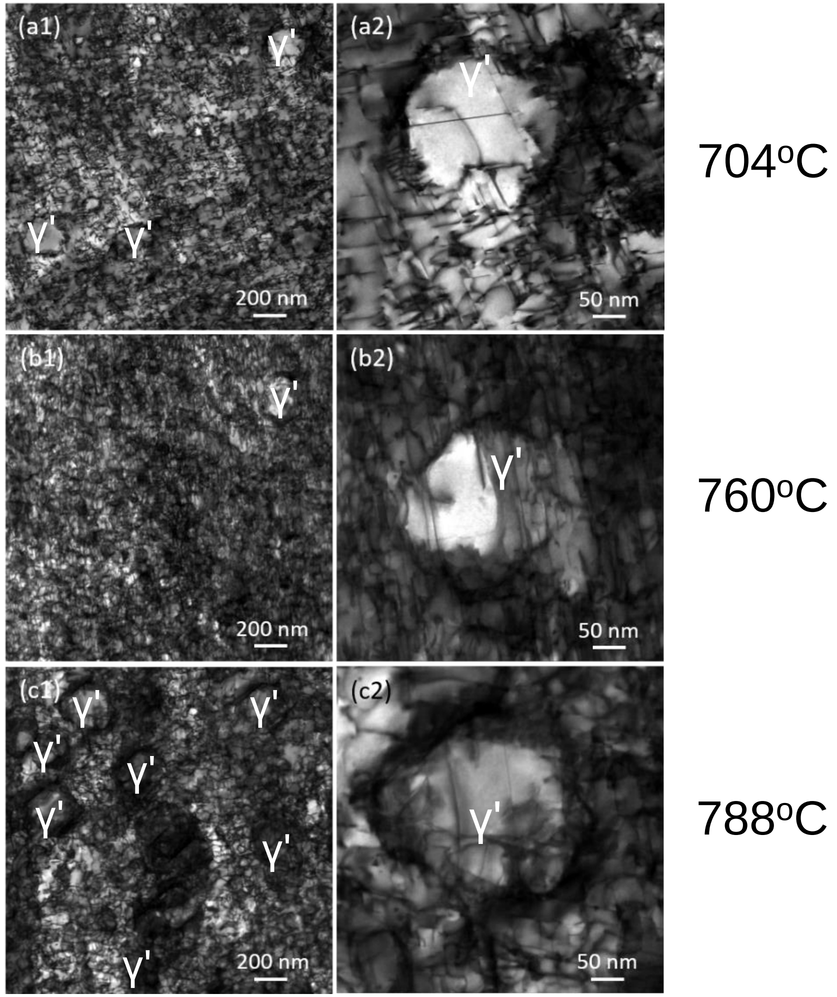
Tensile results of sand cast Haynes 282 ---- dislocation microstructures

$Ni_3(Al,Ti)$ γ’ precipitates



- ❖ Slip bands are dominant microstructure at RT
- ❖ Clustered carbides behaved as obstacles to the dislocation moving
- ❖ Fine-scale γ’ precipitates were sheared by the slip bands

Room temperature



- ❖ Dislocation networks are dominant at elevated temperatures
- ❖ γ’ precipitates had internal stacking faults after interaction with dislocations

Elevated temperature

Future Work

Ni alloys for A-USC

Haynes 282 large sand casting
- Tensile
- Creep
- Low cycle fatigue and Creep-fatigue

Haynes 282 casting cross-weld with 282 filler metal
- Creep
- Thermal aging

Haynes 282 triple-melt forged disk
- Creep
- Environmental high cycle fatigue

IN 740H shielded metal arc welding with Thermanit 263 filler metal
- Creep
- Microstructure characterization

Haynes 282 casting to IN 740H plate dissimilar weld
- Metallography & microhardness
- Tensile
- Creep
- Thermal aging

ComTest Phase 2 components
- TBD

Microstructure characterization of Ni alloys to elucidate the correlations between material microstructures and mechanical properties

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