Materials for Advanced Ultra-Supercritical Steam Service - Turbines

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2 x 800 MW Lignite-Fired Power Plant Schwarze Pumpe, Germany

HMN-Series (High-, Intermediate- and Low-Pressure) Steam Turbine
for Combined-Cycle and Steam Power Plants

Acknowledgements – Funding, U.S. Department of Energy – Office of Fossil Energy

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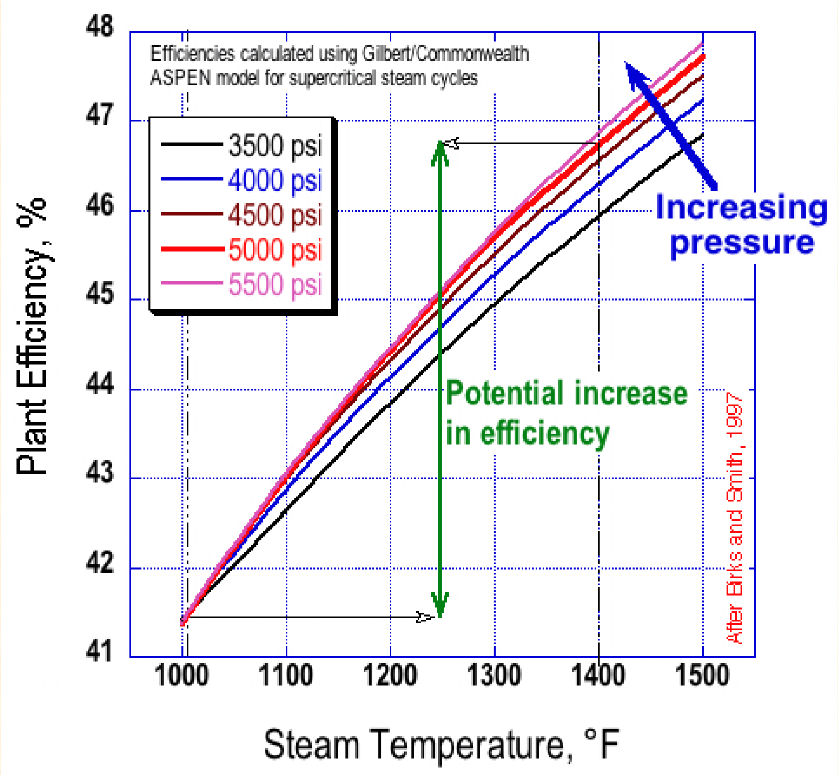
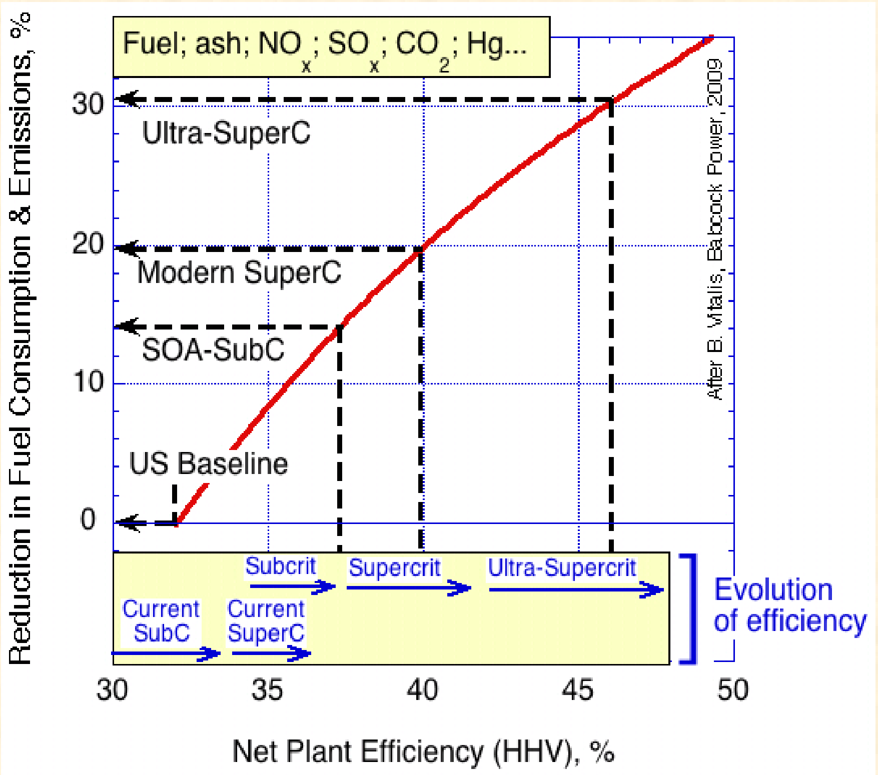
Acknowledgements – Collaboration

- Paul Jablonski, NETL/Albany (OR) Casting and Processing

Increasing Steam Temperature and Pressure Increases Thermal Efficiency and Decreases Emissions for Advanced UltraSuperCritical (A-USC) Steam Technology





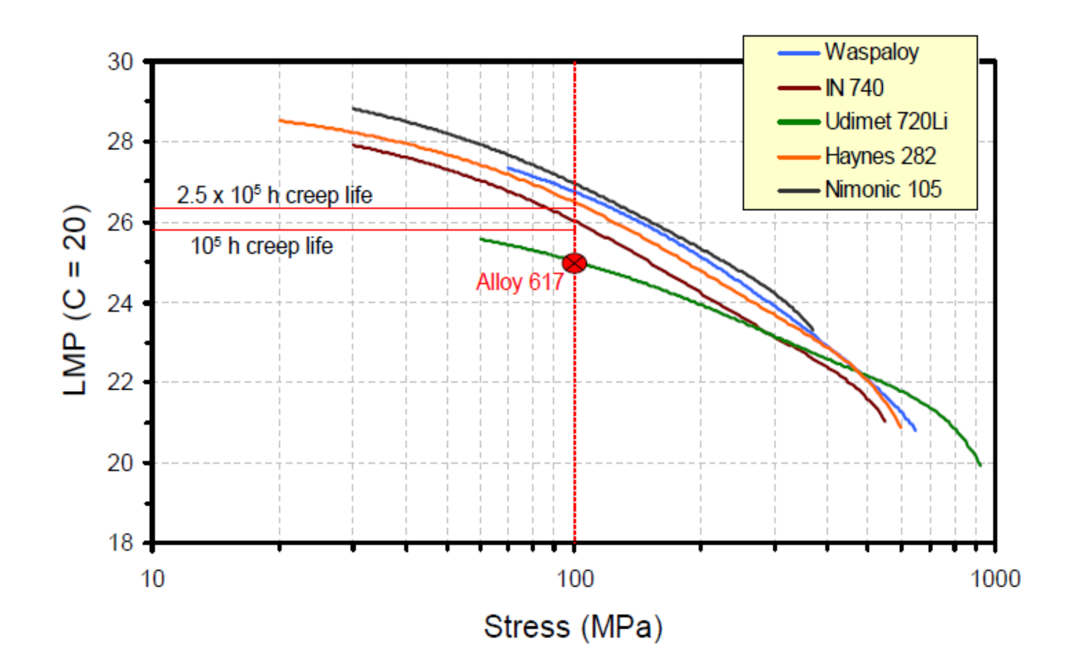
"Least Regret" Strategy for CO_2 Reduction (Viswanathan and Shingledecker, EPRI Conf., Santa Fe, NM, Aug. 2010)

Compositions of Ni-based superalloys being considered for A-USC steam turbine application

Alloy	Ni	Cr	Co	Mo	Nb	Ti	Al	Mn	Si	C
NI 105	bal	14.85	20.0	5.0	-	1.1	4.7	0.5	0.5	0.15
HR 282	bal	19.5	10.0	8.5	-	2.1	1.5	0.15	0.15	0.07
IN 740	bal	25.0	20.0	0.5	1.5	1.5	1.3	0.3	0.3	0.03
Alloy 263	bal	20.0	20.0	5.8	-	2.1	0.35	0.5	0.35	0.07

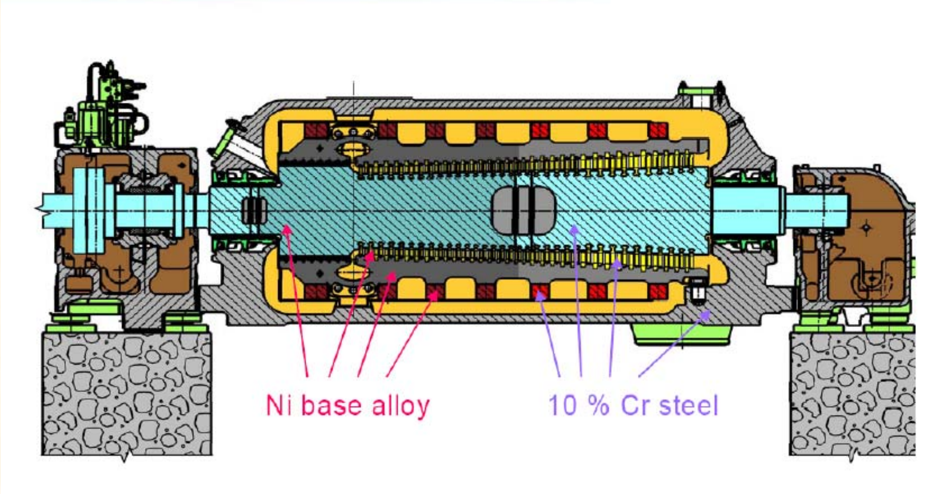
A-USC Turbine Designs Need Ni-based Superalloys (rotors, blading, casing)

Wrought Ni-based superalloys (NI 105 and HR 282) have creep-strength needed for rotors and blading to last 250,000h



Consortium Phase 1 Result

Alstom HP Turbine Concept



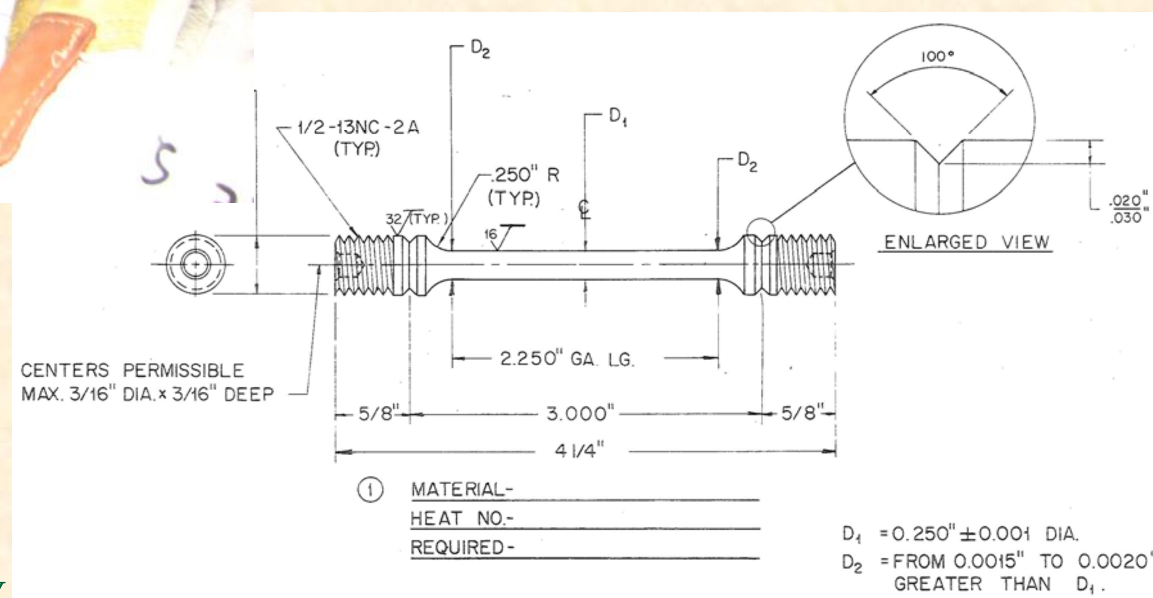
Cast Ni-based superalloys were needed for turbine casing

Materials Selection for A-USC Steam Turbine Components - Summary

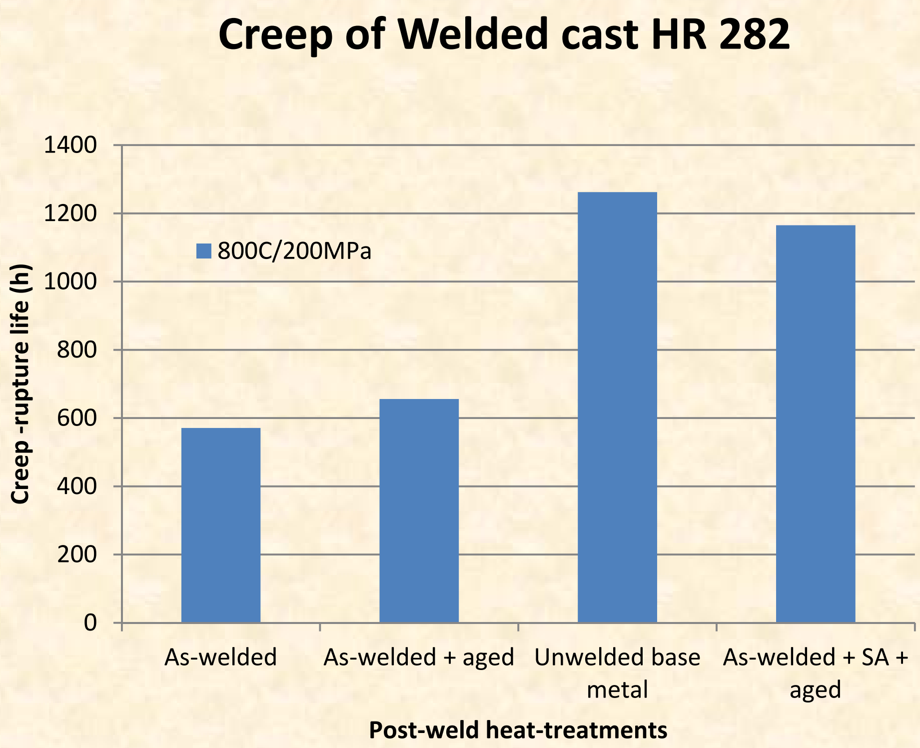
- Blading – HR 282, NI 105 (wrought)
- Bolting – NI 105 (wrought)
- Rotors – HR 282 (wrought)
- Casing – HR 282, HR 263 (cast)

Testing of Narrow-gap GTAWs of Cast HR 282 supplied by GE

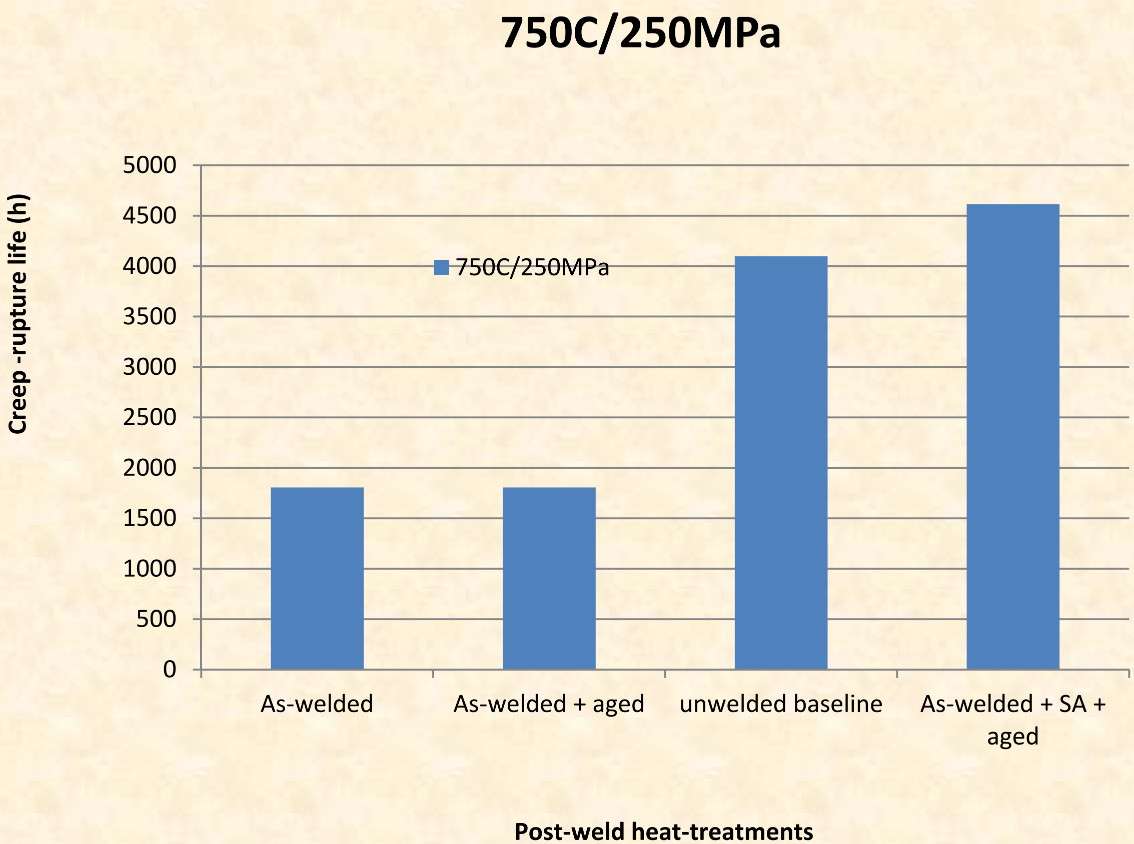
- 18 cross-weld specimens have been machined
- Stress-rupture creep testing is underway



Welded HR 282 – Creep at 800C/200 MPa



Welded HR 282 – Creep at 750C/250 MPa



Welded HR 282 – Creep at 800C/200 MPa

As-welded

Welded + SA
+ aged

Fatigue Testing of Wrought HR 282 Alloy

- A unique facility to provide high-temperature fatigue testing in steam was designed and assembled
- Initial testing encountered some problems that had to be overcome
- Preliminary results of steam and air testing of wrought HR 282 at 800^{o}C are presented

Steam Fatigue Testing Setup

Steam inlet

Thermocouples and steam outlet

Extensometer port in furnace (closed)

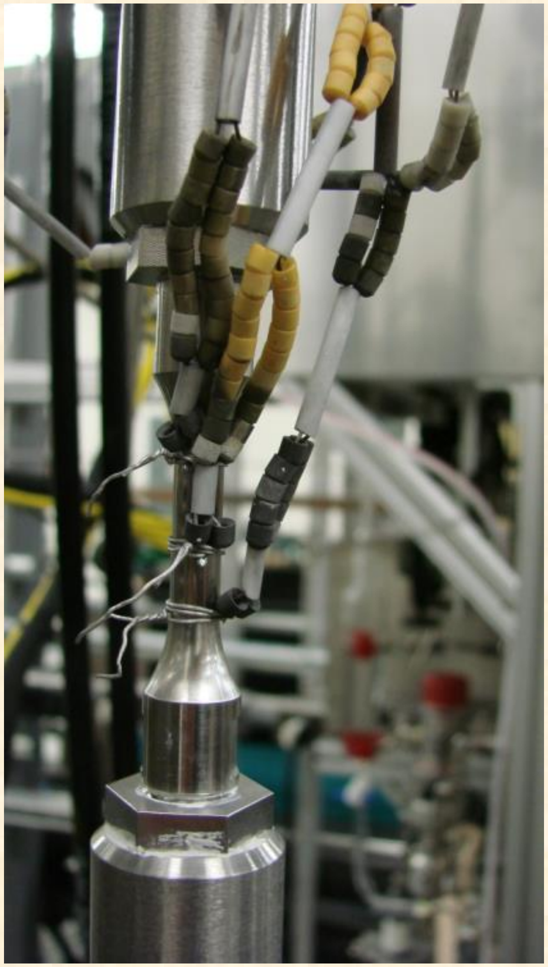
Inconel retort

Water cooled Bellow (on both sides)

Steam Generator
(water chemistry is controlled)

Assembled Load Train at 800^{o}C

More details of assembly



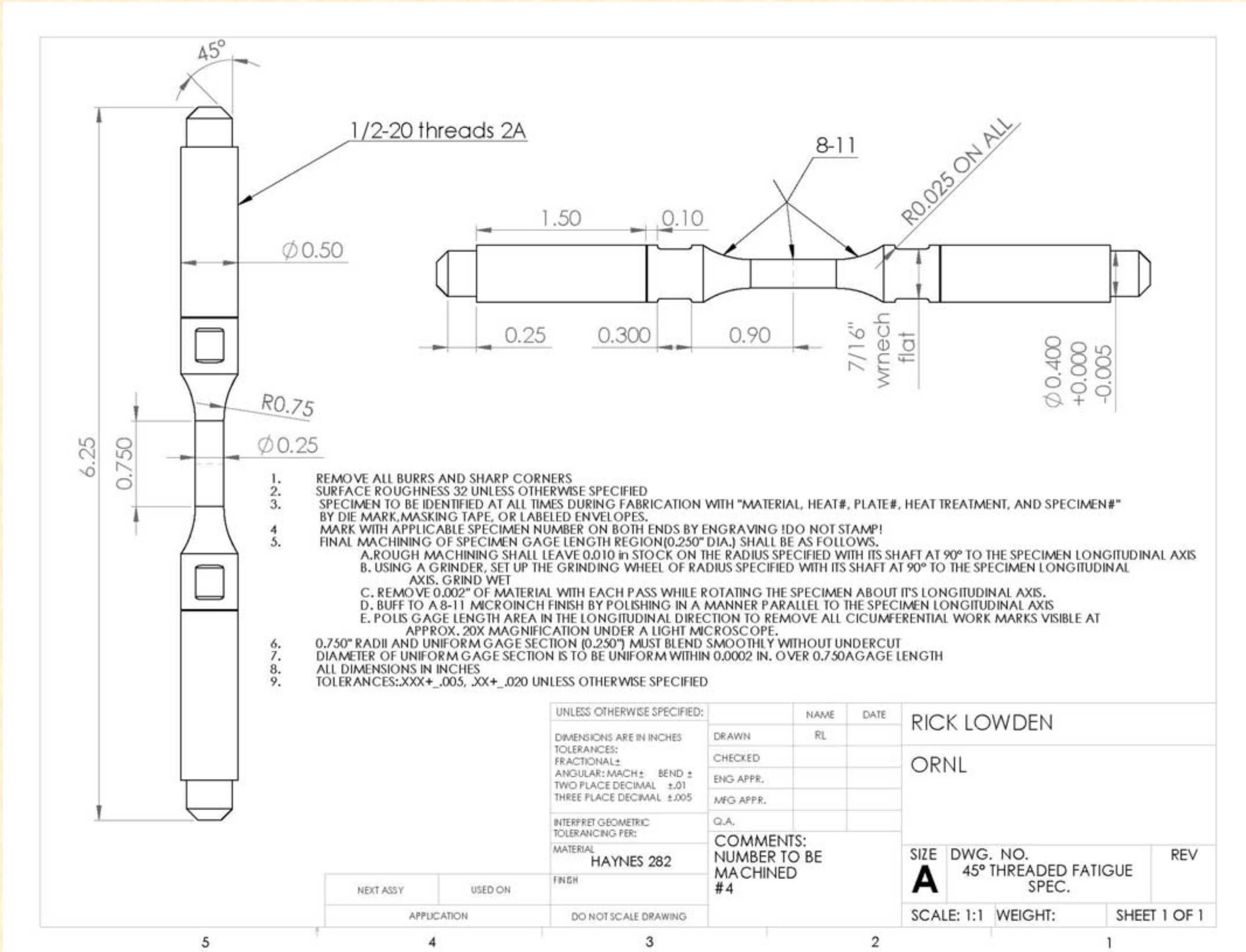
Specimen with three TCs

Top part of load train assembly

Retort

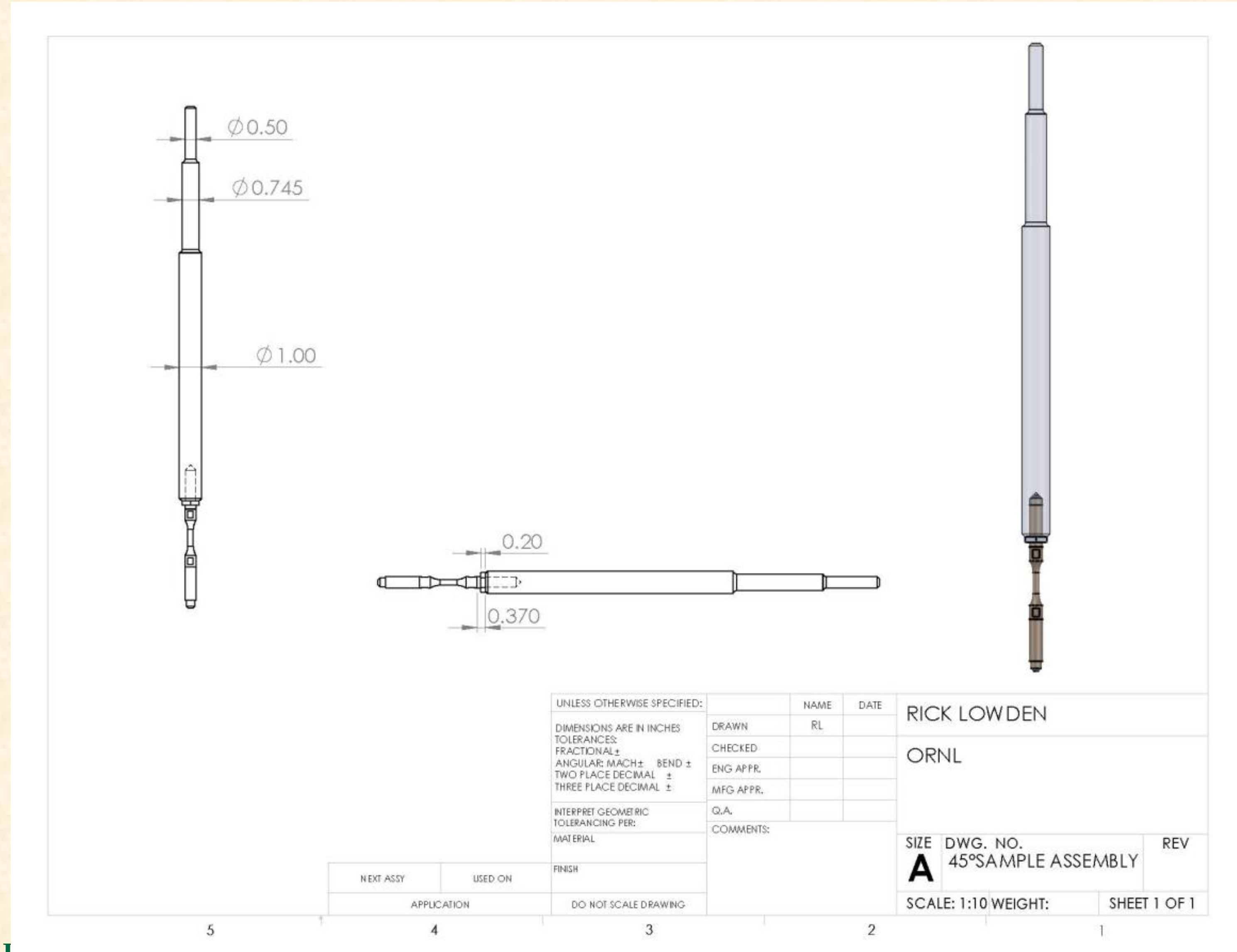
Bellows

Specimen design and machining details

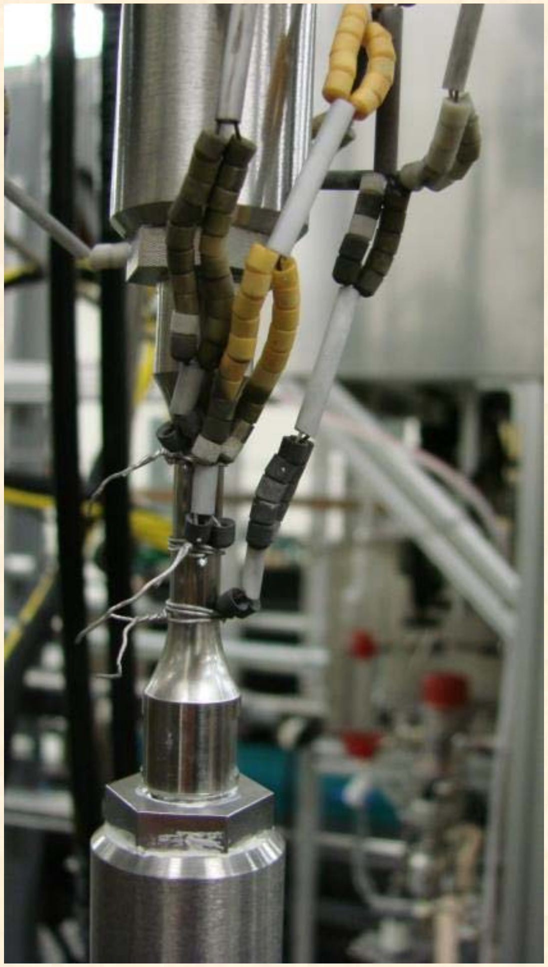


- 45 degree cuts in at the specimen ends to reproduce alignment
- Grooves outside gage section to tighten jamnut and specimen in pullrod (N155)

Pullrod-specimen-jamnut assembly drawing



Initial test details



Specimen with three TCs
(before exposure)

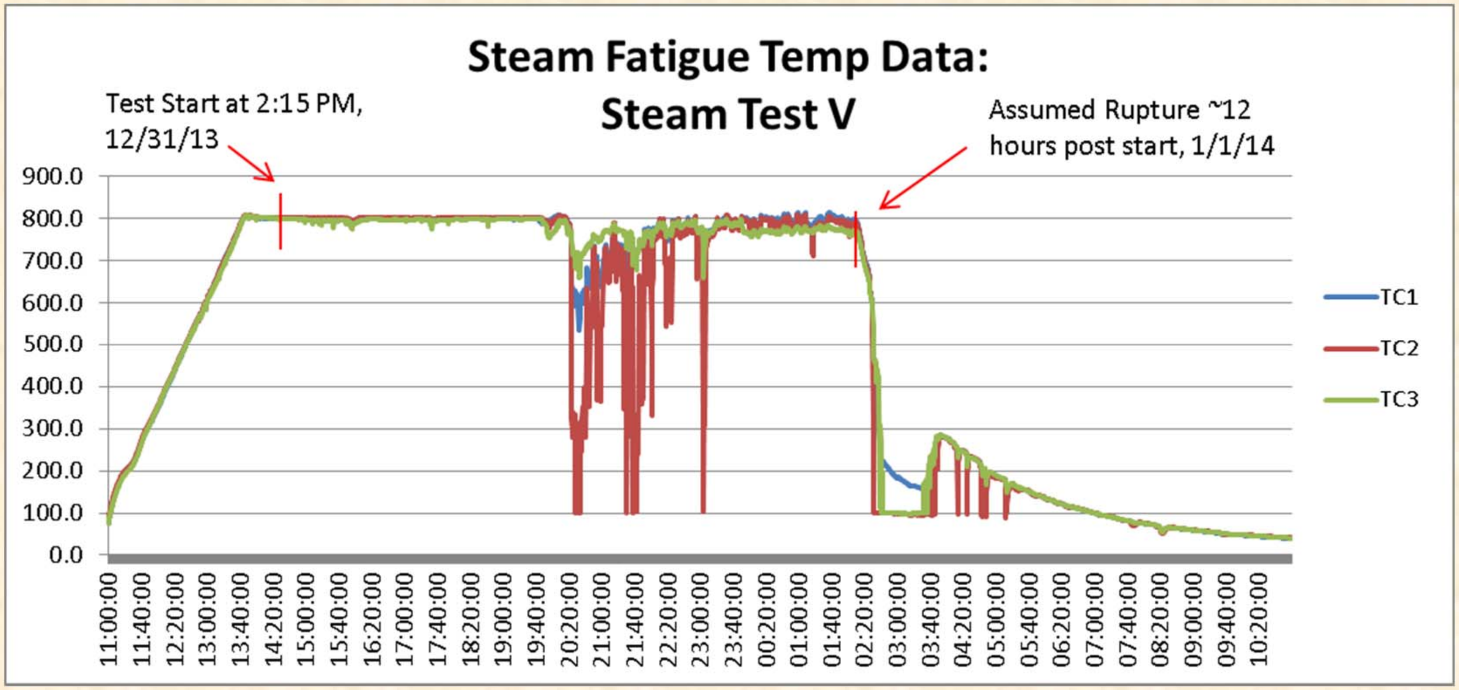
Failed specimen of wrought Haynes 282
T ~ 850^{o}C; 100% steam; ν = 10 Hz
σ_{max} = 55 ksi; R = -1
(expected fatigue limit is ~48 ksi in air in this condition)
N_f = 184,659 cycles

Machine alignment

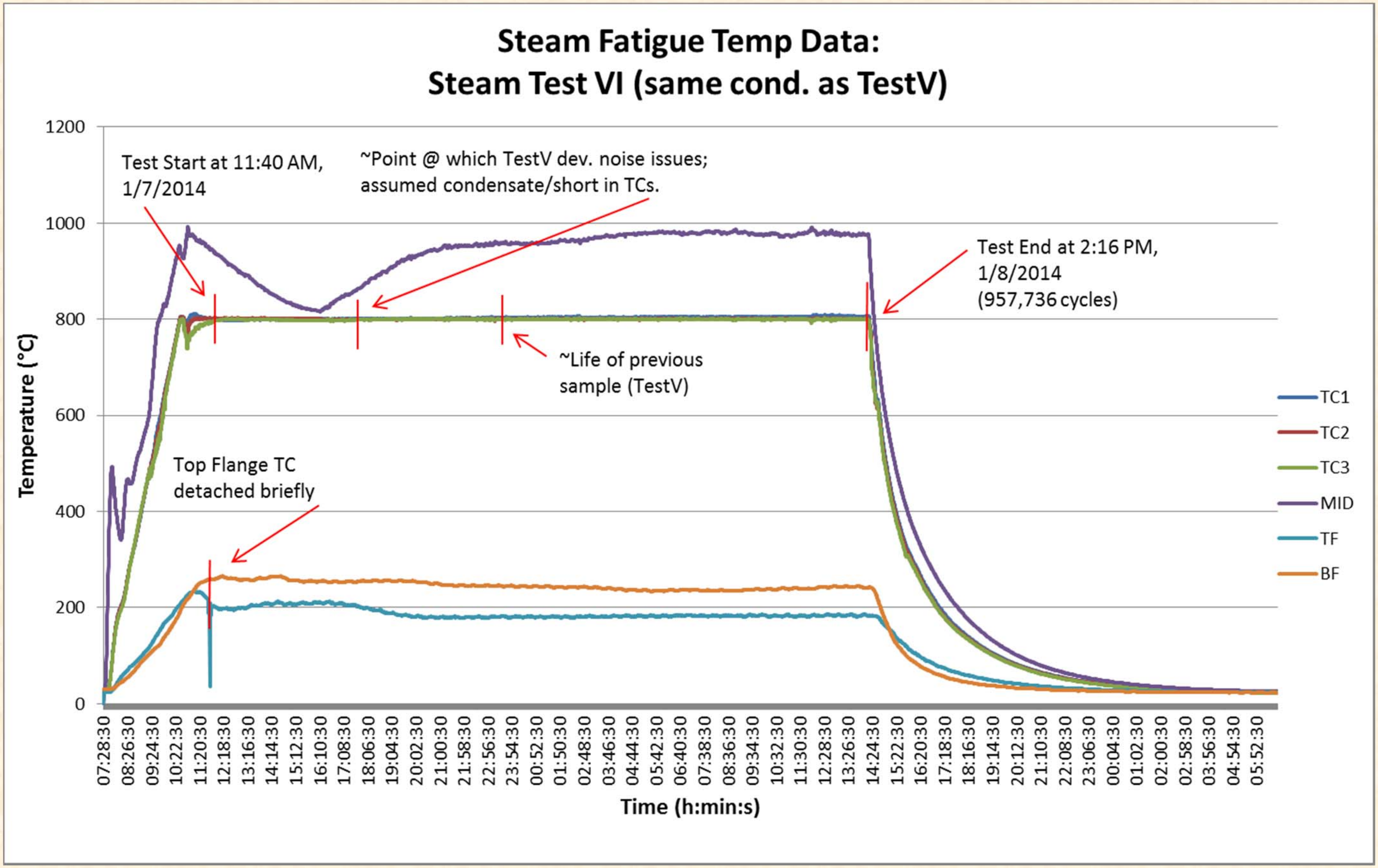
Machine aligned by instrumented specimen (pictured)
Bending strain < 5% uniaxial strain as per ASTM standard

Several iterations required + problems solved

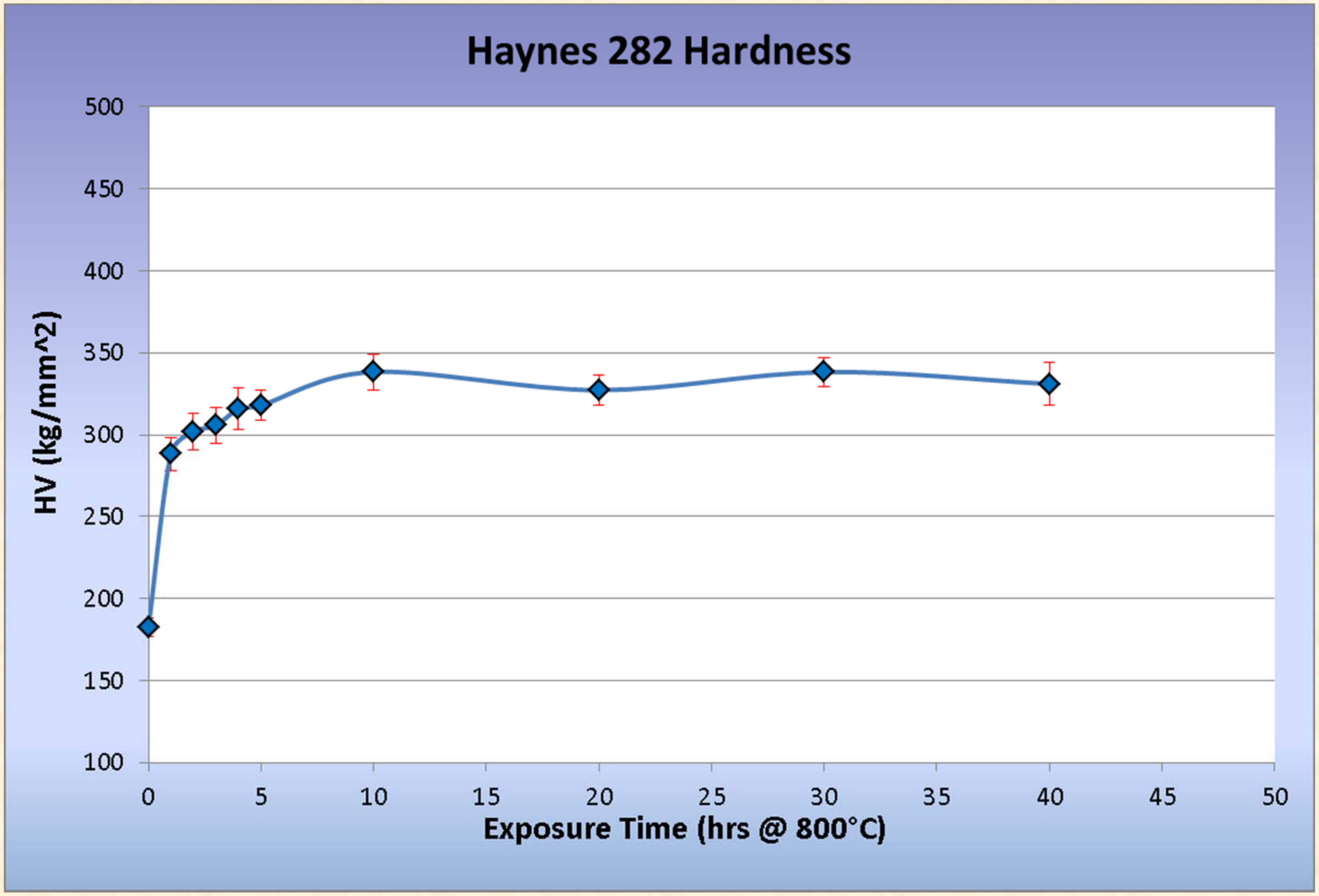
- Thermocouple readings were off
- Condensation in the bottom of the specimen
- Temperature instability
- Soaking time at temperature to be standardized
- Last problem to be resolved



First good fatigue test in steam

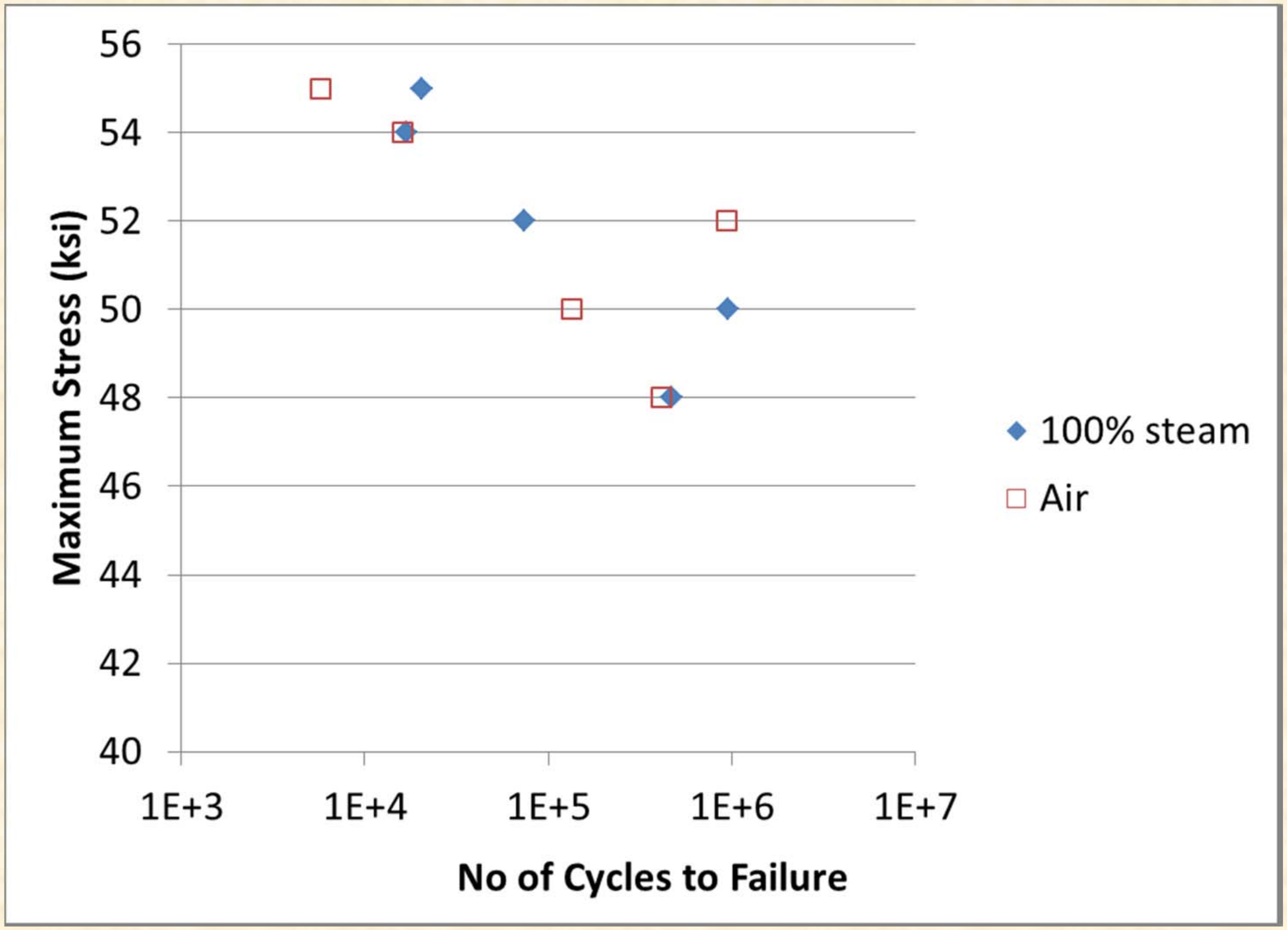


Hardness evolution with time at 800°C



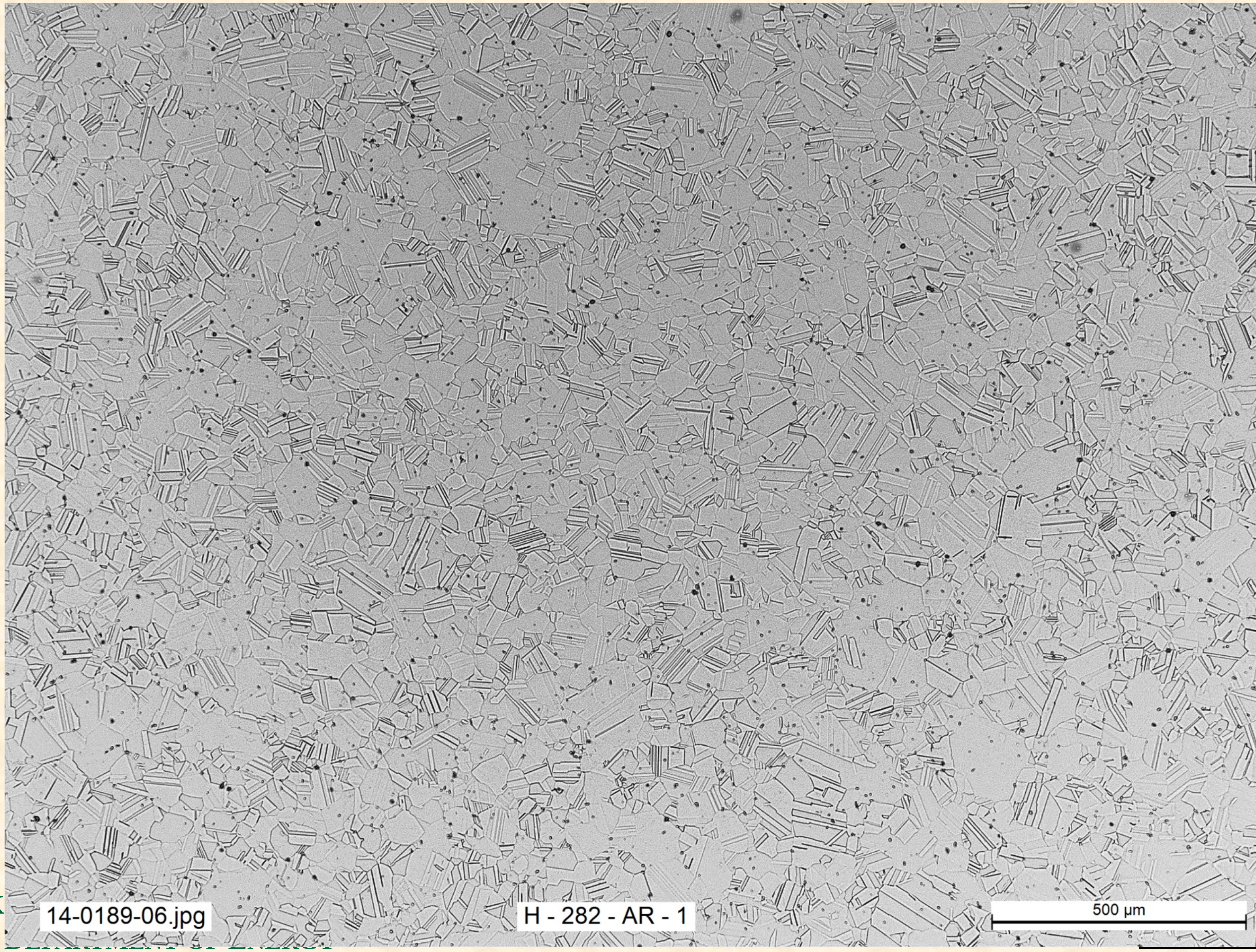
- ~90% peak hardness reached after 1 hr soak so this soak time was used.

Fatigue testing results to date

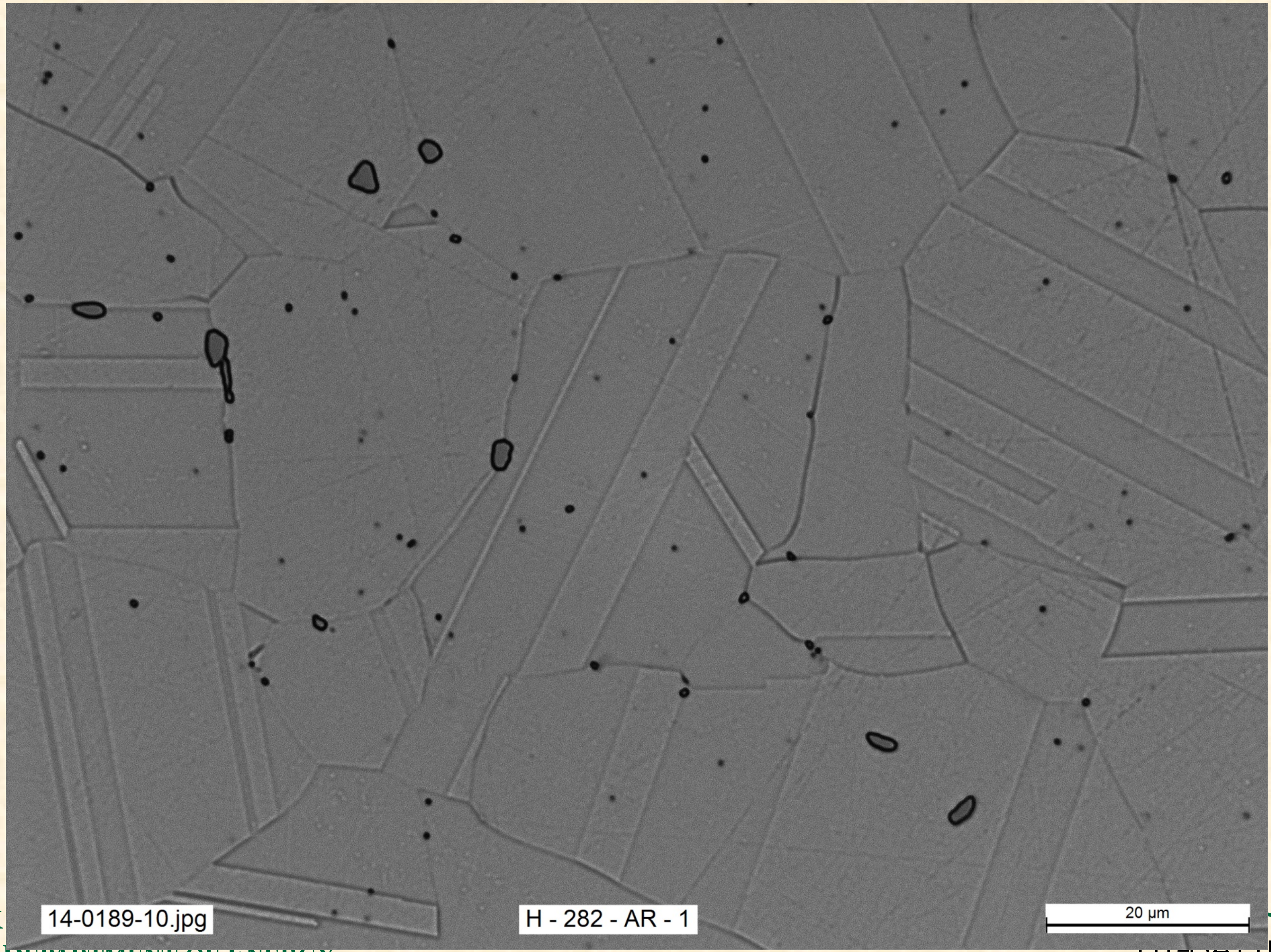


- No clear trend in terms of effect of steam environment
- Relatively longer lifetimes are sub-surface crack initiation
- Relate the fatigue lifetime variability to microstructural variability

Optical microstructure – Haynes 282



Optical microstructure – Haynes 282

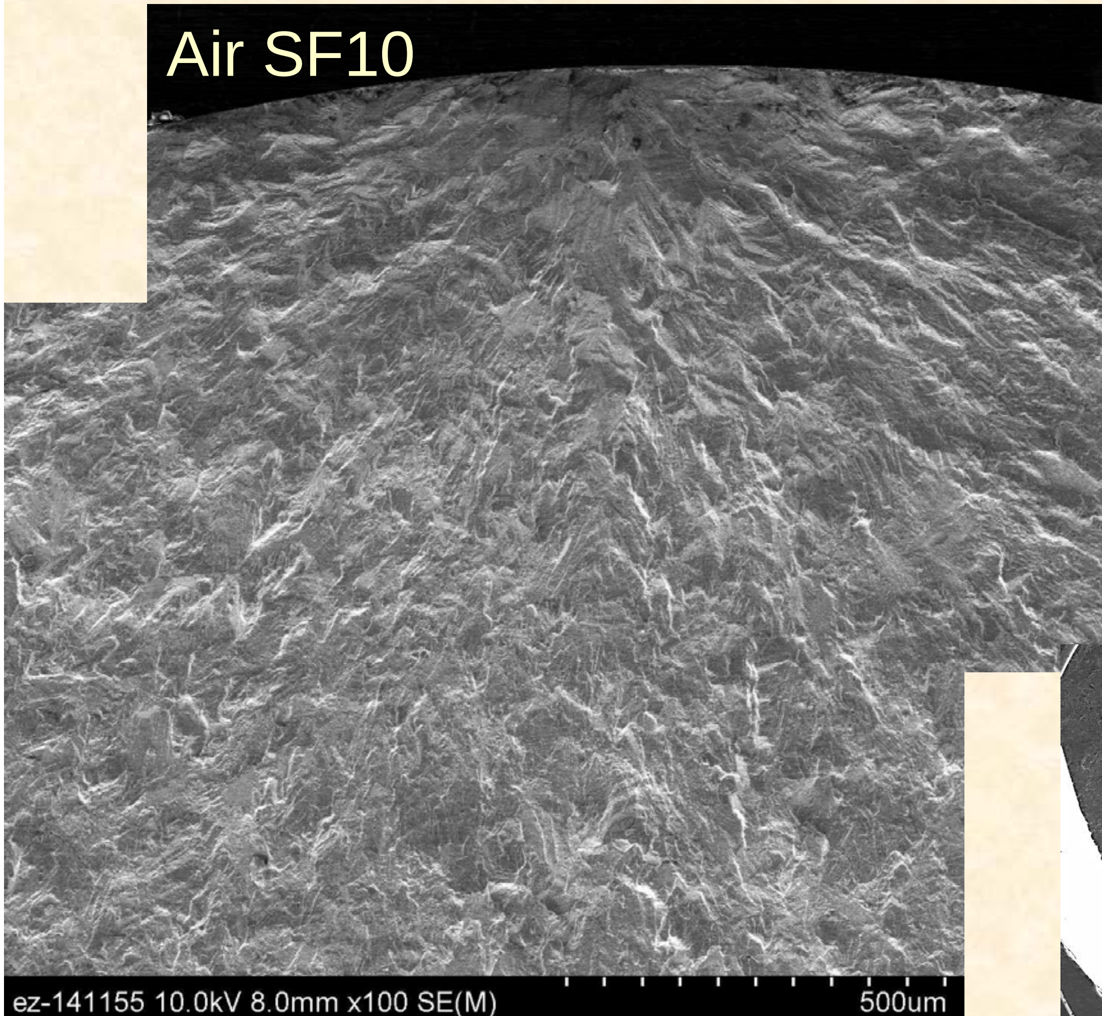


Fracture Surface Images

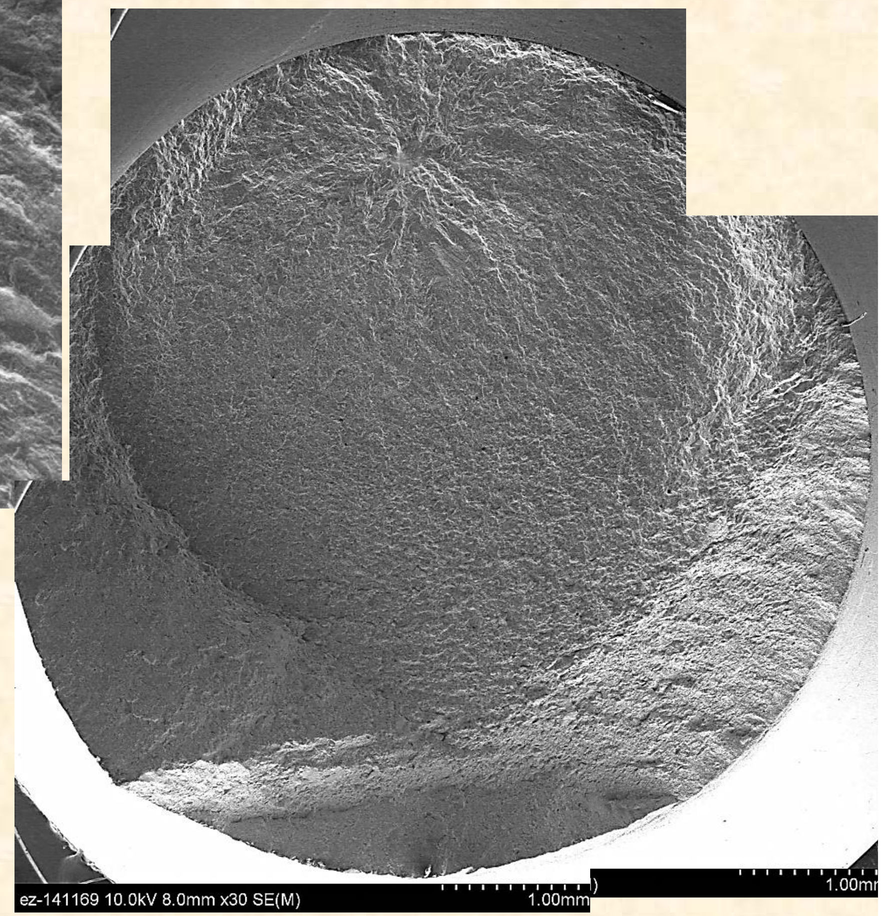
50 ksi; R = -1

N_f (air) = 133,761 cycles

N_f (100% steam) = 957,736 cycles



Steam SF12

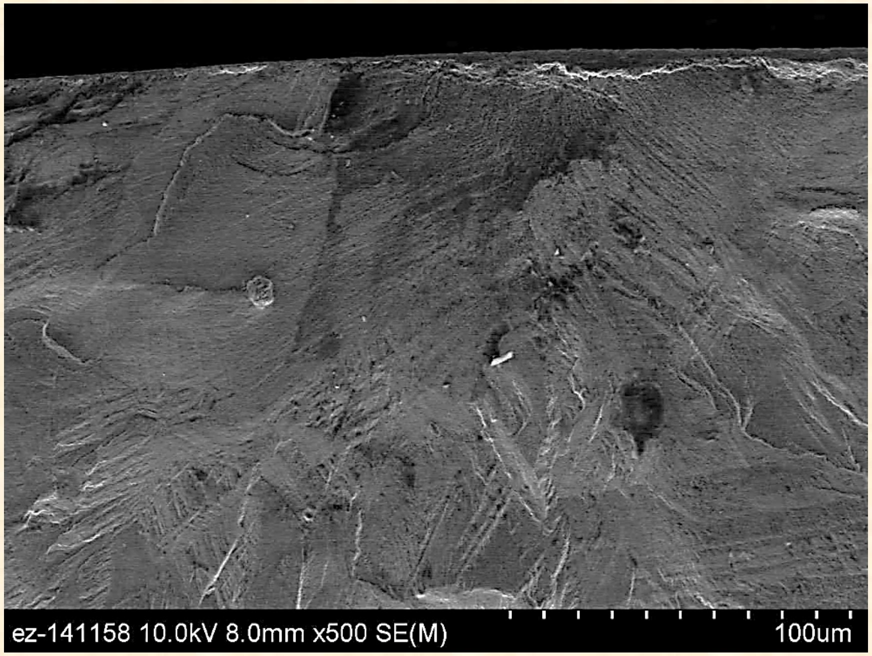


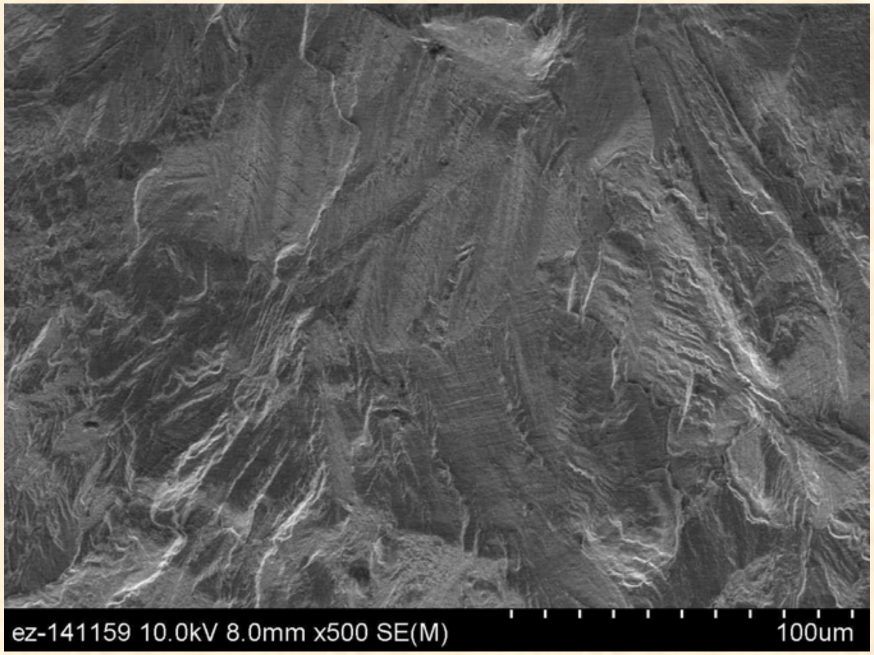
Fracture Surface Images

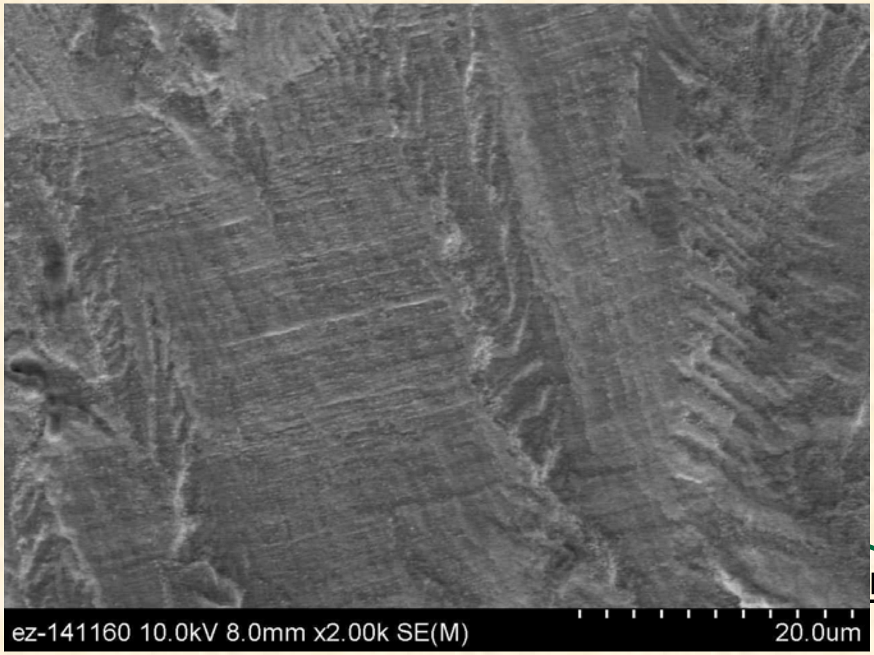
50 ksi; R = -1

N_f (air) = 133,761 cycles

Air SF10





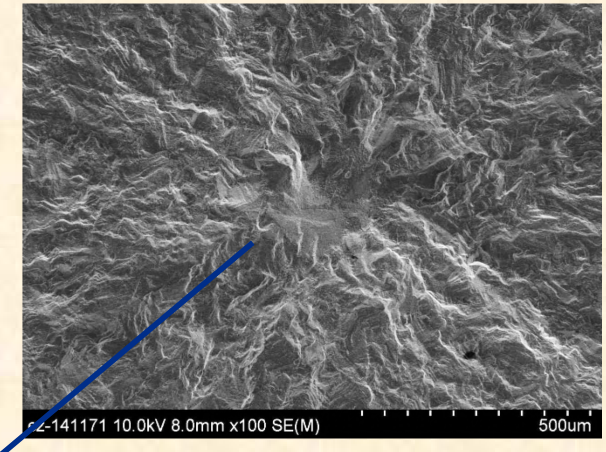


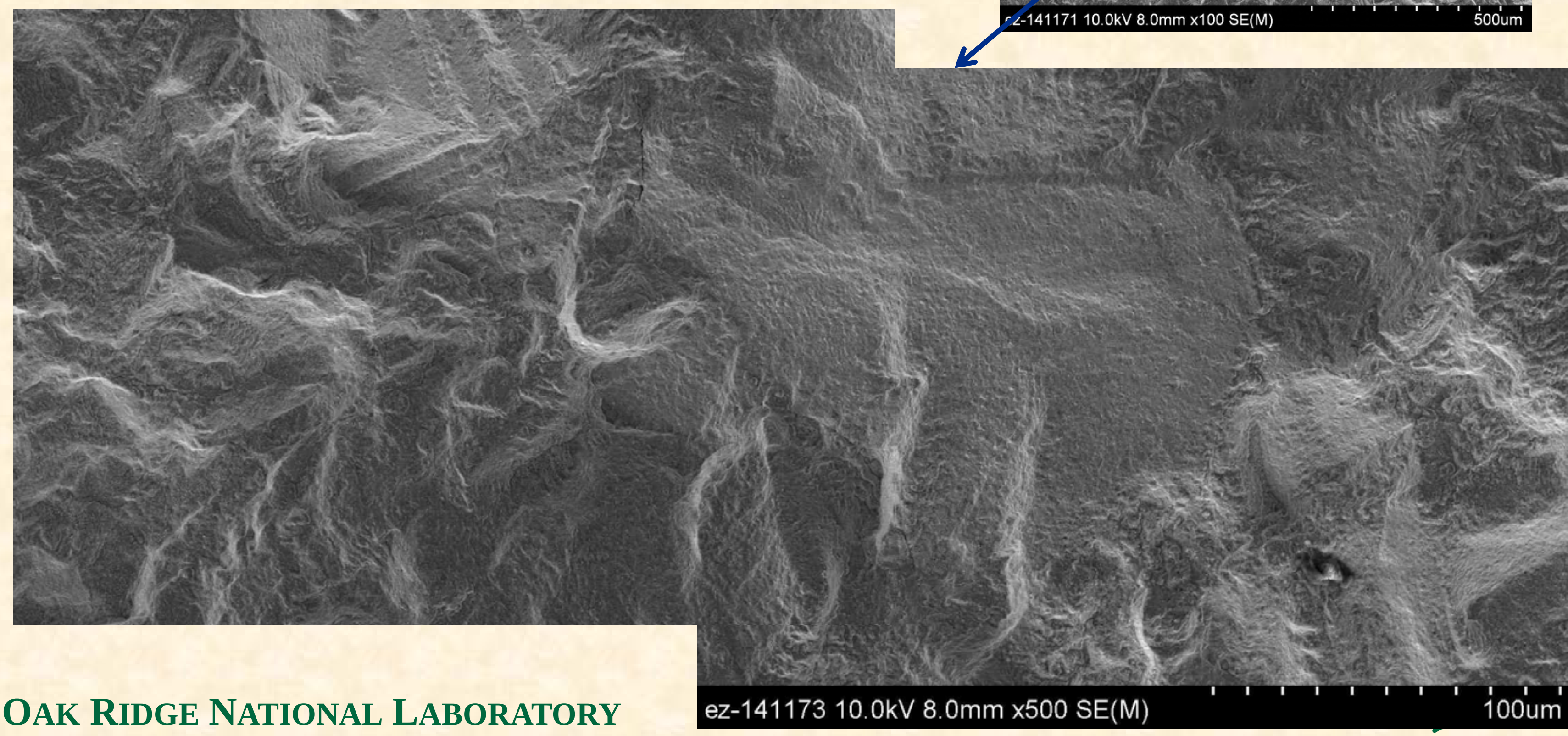
Fracture Surface Images

50 ksi; R = -1

N_f (100% steam) = 957,736 cycles

Steam SF12, crack initiation site

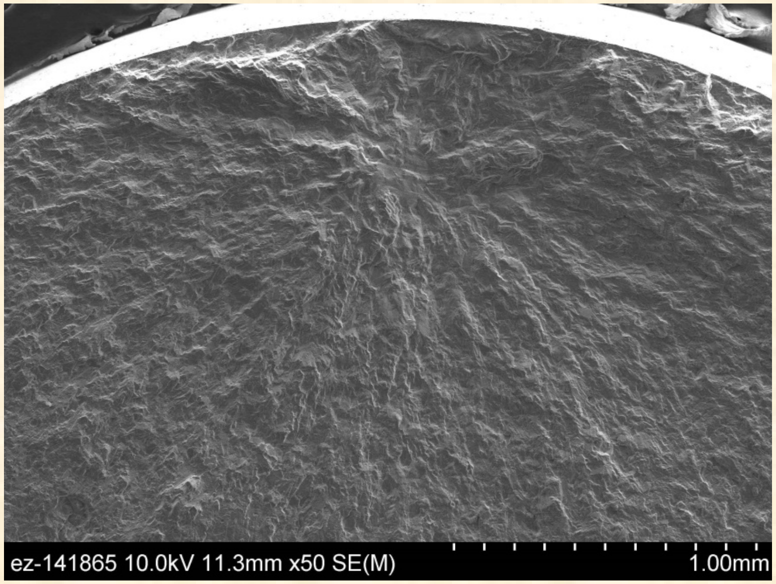


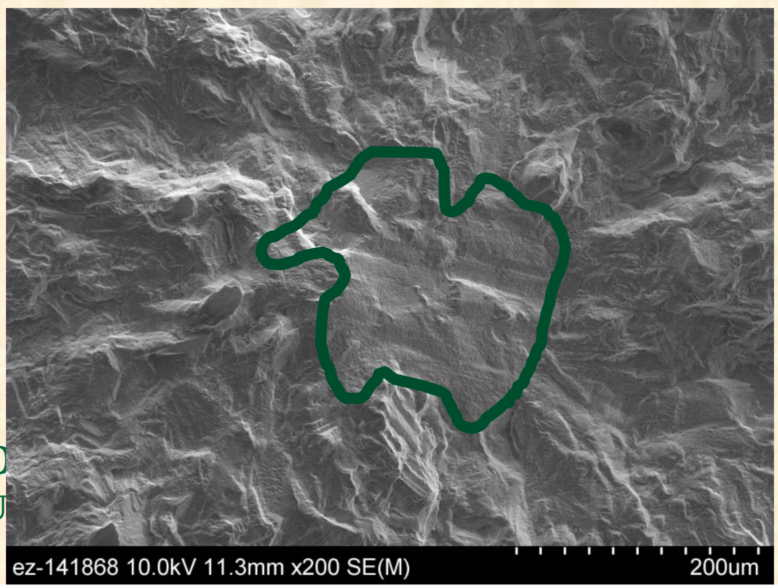


Fracture Surface Images

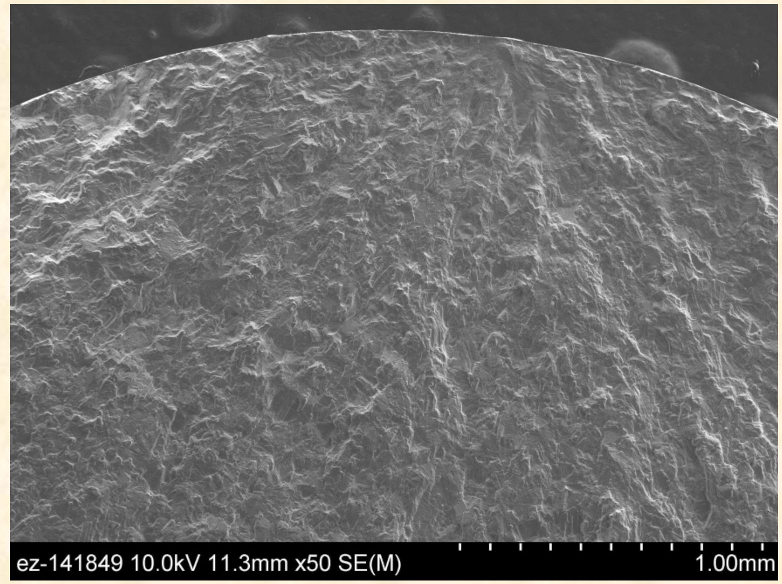
52 ksi; R = -1

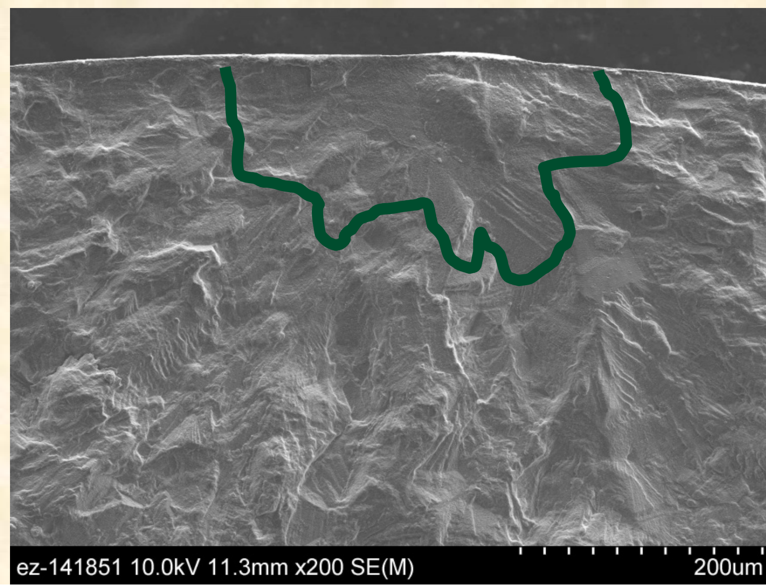
N_f (air) = 936,659 cycles





N_f (100% steam) = 73,798 cycles





DOE/FE 2014 Project Review – FY14 Milestones

- 2014 project milestone – Analyze weldment data in terms of weld-reduction factors (Feb, 2014) - complete
- 2014 project milestone – Evaluate the effect of steam on fatigue behavior of HR 282 (June, 2014) – in progress
- 2014 project milestone – Prepare summary report on all test results to date on large cast heats (Sept. 2014) – in progress

Summary

- Cast HR 282 shows good weldability, and preliminary creep-rupture properties of the weldment that are equivalent to the base-metal at 750-800^{o}C with proper post-weld heat-treatment.
- Unique and complex steam fatigue test facility was assembled and operated at ORNL
- Preliminary HCF testing of wrought HR 282 at 800^{o}C in steam and air shows no adverse effects of steam so far.
- Microstructural effects on fracture site appear to most important effect of fatigue on HR 282 found to date