Overview of Creep Strength and Oxidation of Heat-Resistant Alloy Sheets and Foils for Compact Heat-Exchangers

Philip J. Maziasz, J.P. Shingledecker,
B.A. Pint, N.D. Evans, K.L. More, and E. Lara-Curzio

Metals and Ceramics Division

Oak Ridge National Laboratory

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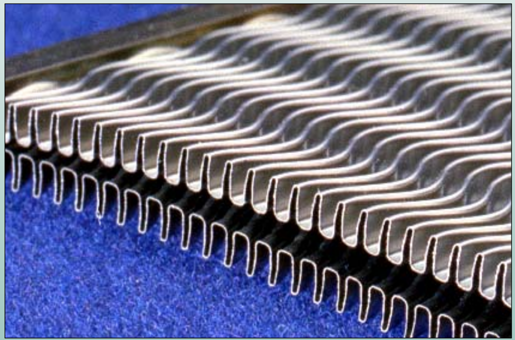
Recuperators Are Compact Heat Exchanges that Boost the Efficiency of Microturbines

Capstone 60 kW
Microturbine

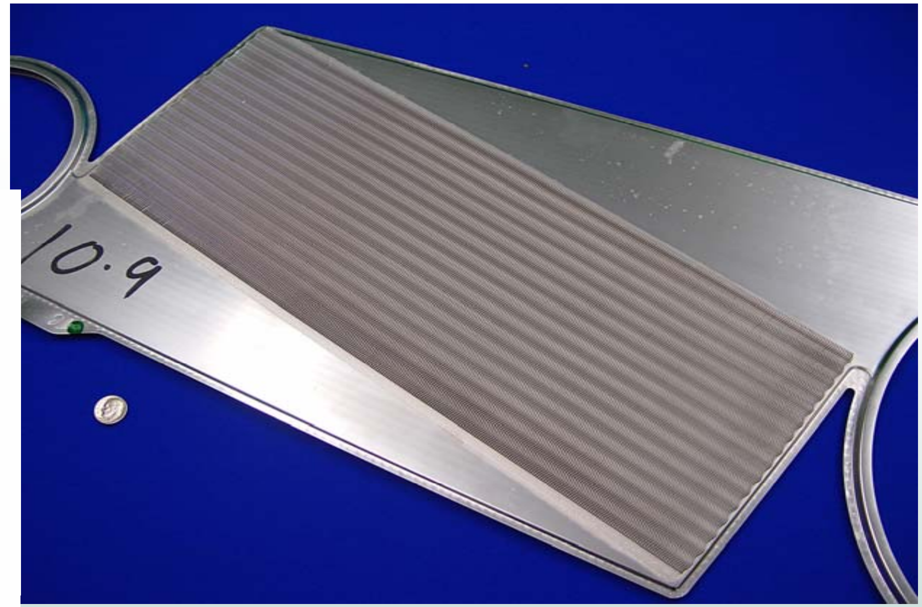
Capstone



Primary Surface
Recuperator (PSR)

Recuperators Are Compact Heat Exchanges that Boost the Efficiency of Microturbines

Ingersoll Rand 70 kW PowerWorks



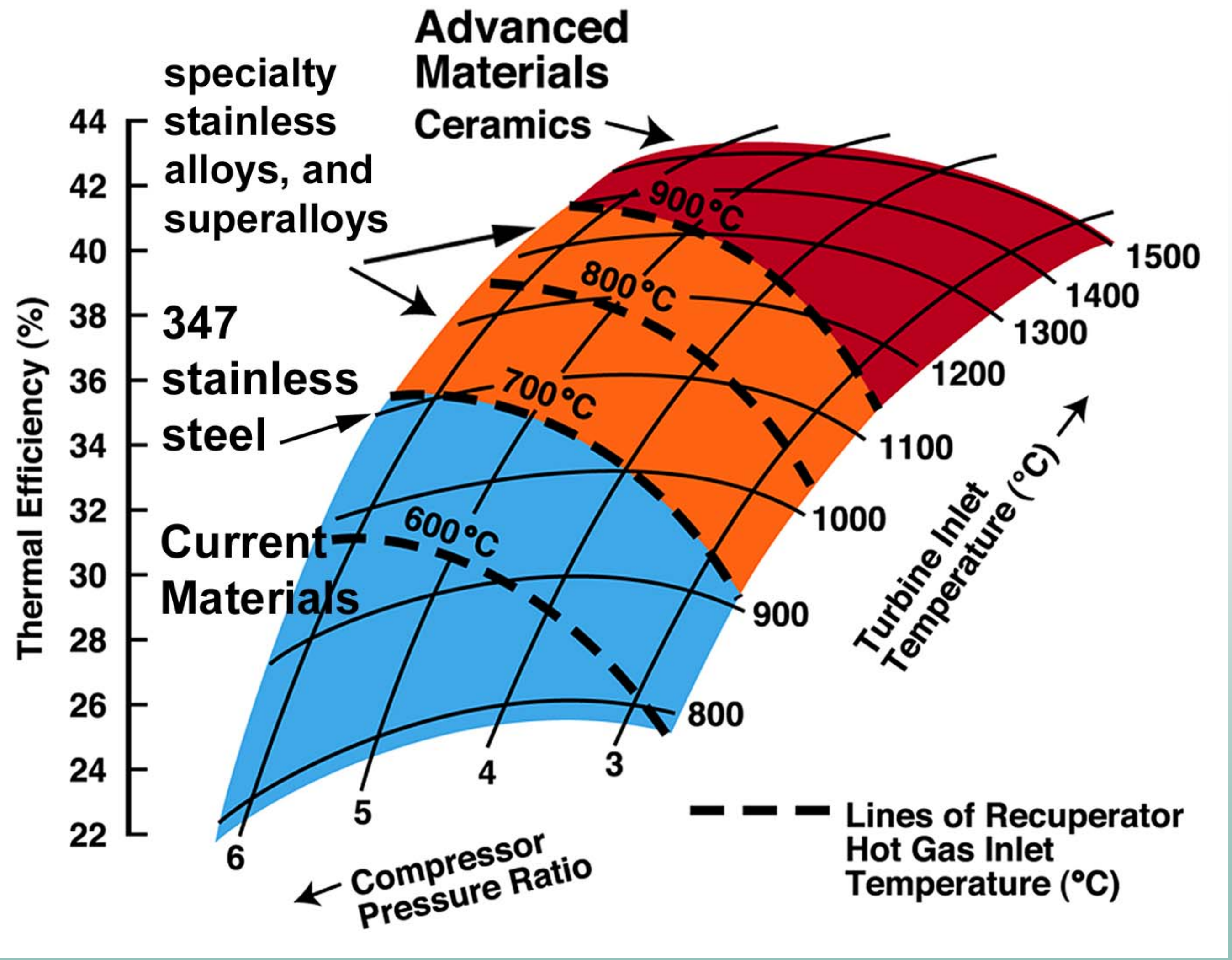
Brazed Plate and Fin Recuperator (PFR)

Background

Main parameters to consider for the selection of materials for microturbine recuperators

- Temperature
- Environment (combustion gases can lead to corrosion)
- Mechanical Stress (pressure differential can induce creep deformation)

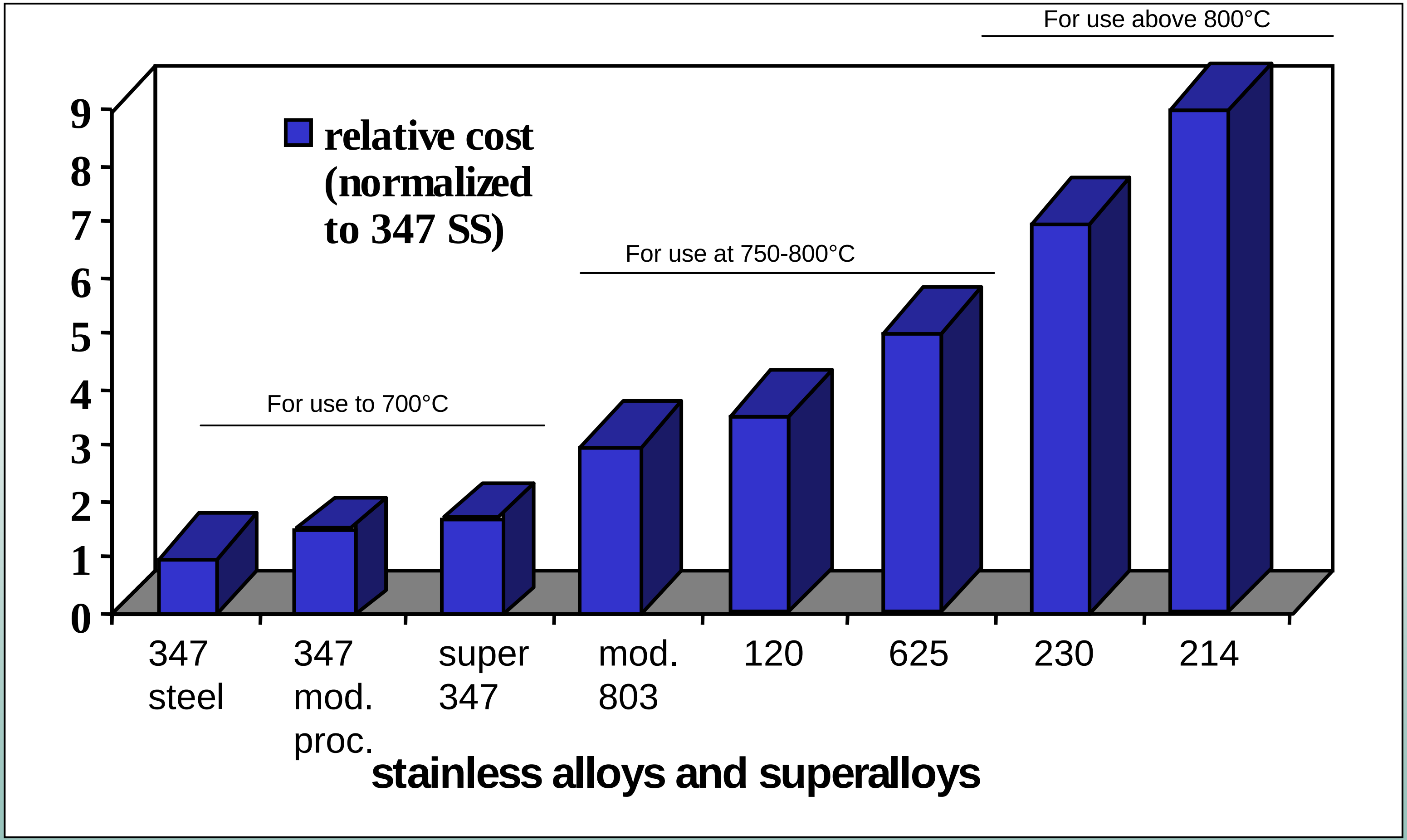
Materials Selection is Determined by the Recuperator Hot-Gas Inlet Temperature and by the Alloy Capabilities



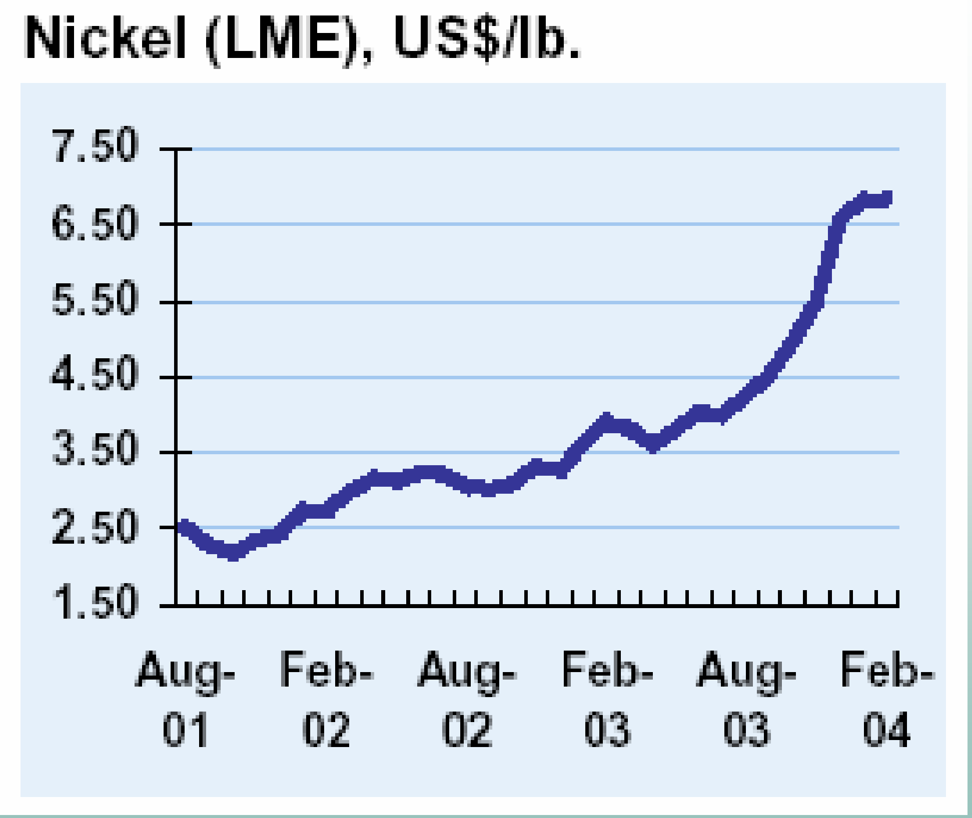
Alloy Compositions (wt.%)

- 347 steel – Fe -18Cr-9.5Ni-1.5Mn-0.25Mo-0.04C-0.63Nb
- ORNL mod 347 steel – 347 + Mn + N + Cu
- HR120 – Fe -25Cr-33Ni-1Mn-1Mo-0.05C-0.7Nb-0.2N
- NF709 – Fe – 20.5Cr-25Ni-1Mn-1.5Mo-0.07C-0.26Nb-0.15N
- Alloy 625 – Ni-22Cr-3.2Fe-9Mo-3.6Nb-0.02C-0.23Ti-0.16Al
- HR230 – Ni -22Cr -3Fe-2Mo-5Co-14W-0.1C-0.3Al

Alloy Selection for Advanced Microturbine Recuperators is Based on Balancing Relative Cost and Performance

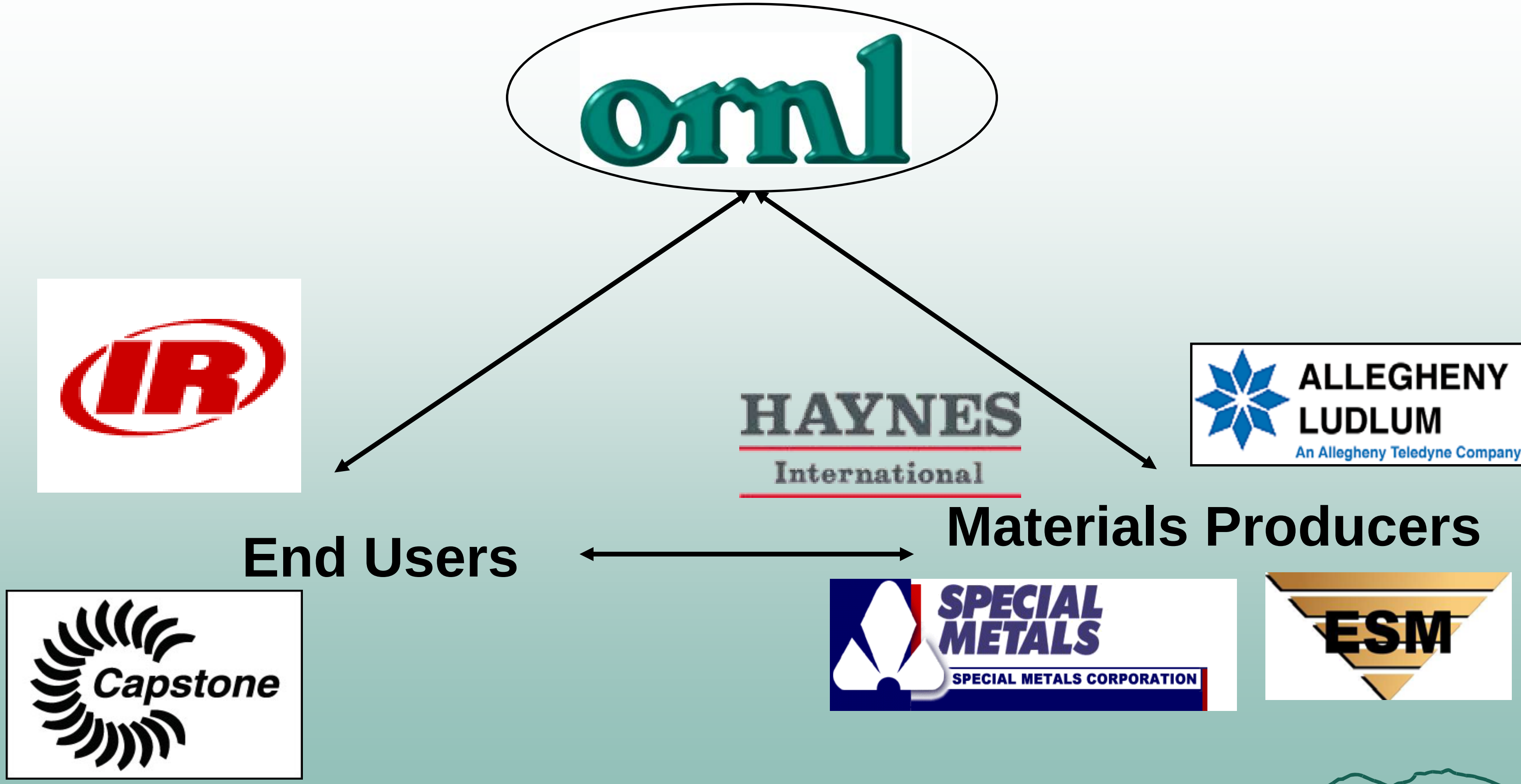


The cost of Ni has risen, adding more cost to higher performance, heat-resistant alloys

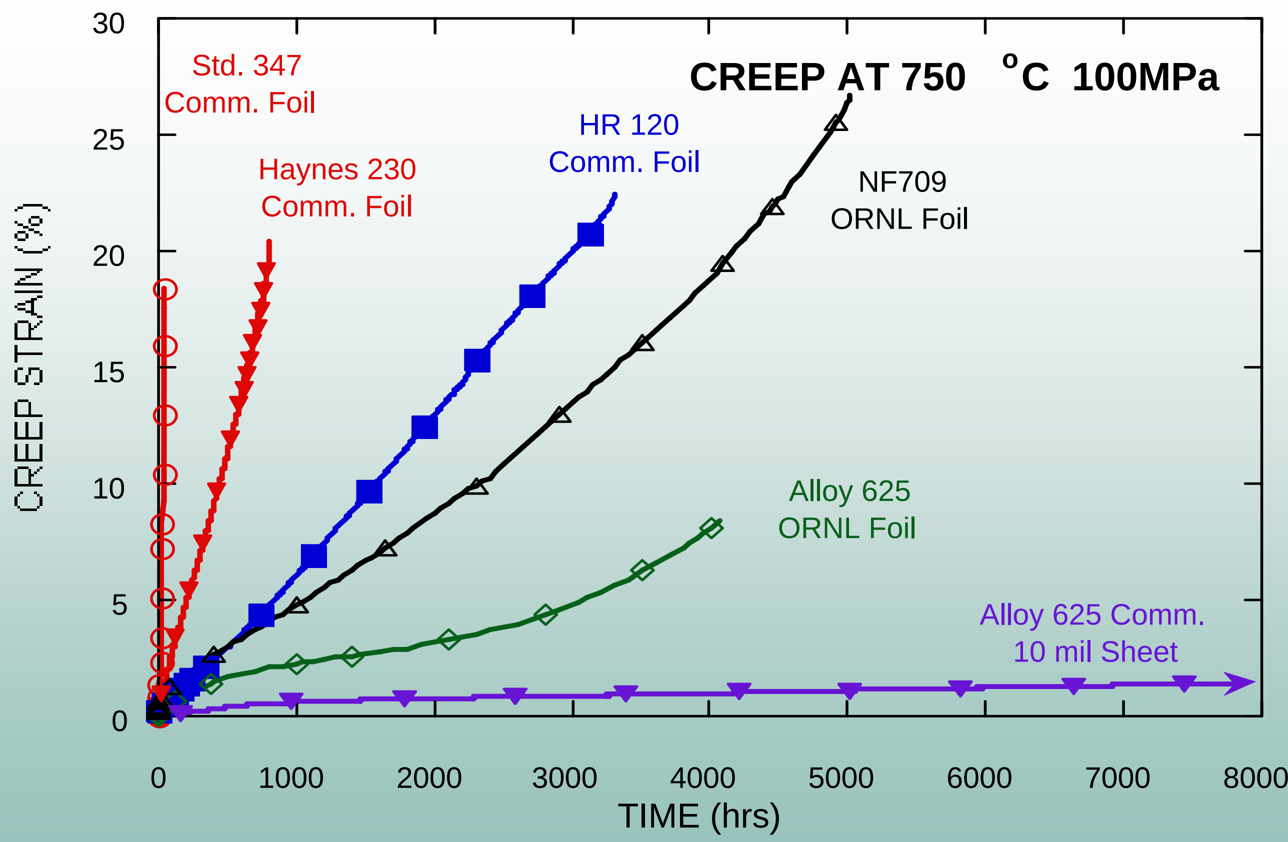


ORNL Characterizes the Properties of Commercial Foil and Sheet Stainless Steels and Alloys Used To Make Recuperators

Materials R&D Capabilities and Expertise



Several commercial heat-resistant alloys have better creep-rupture resistance than 347 steel



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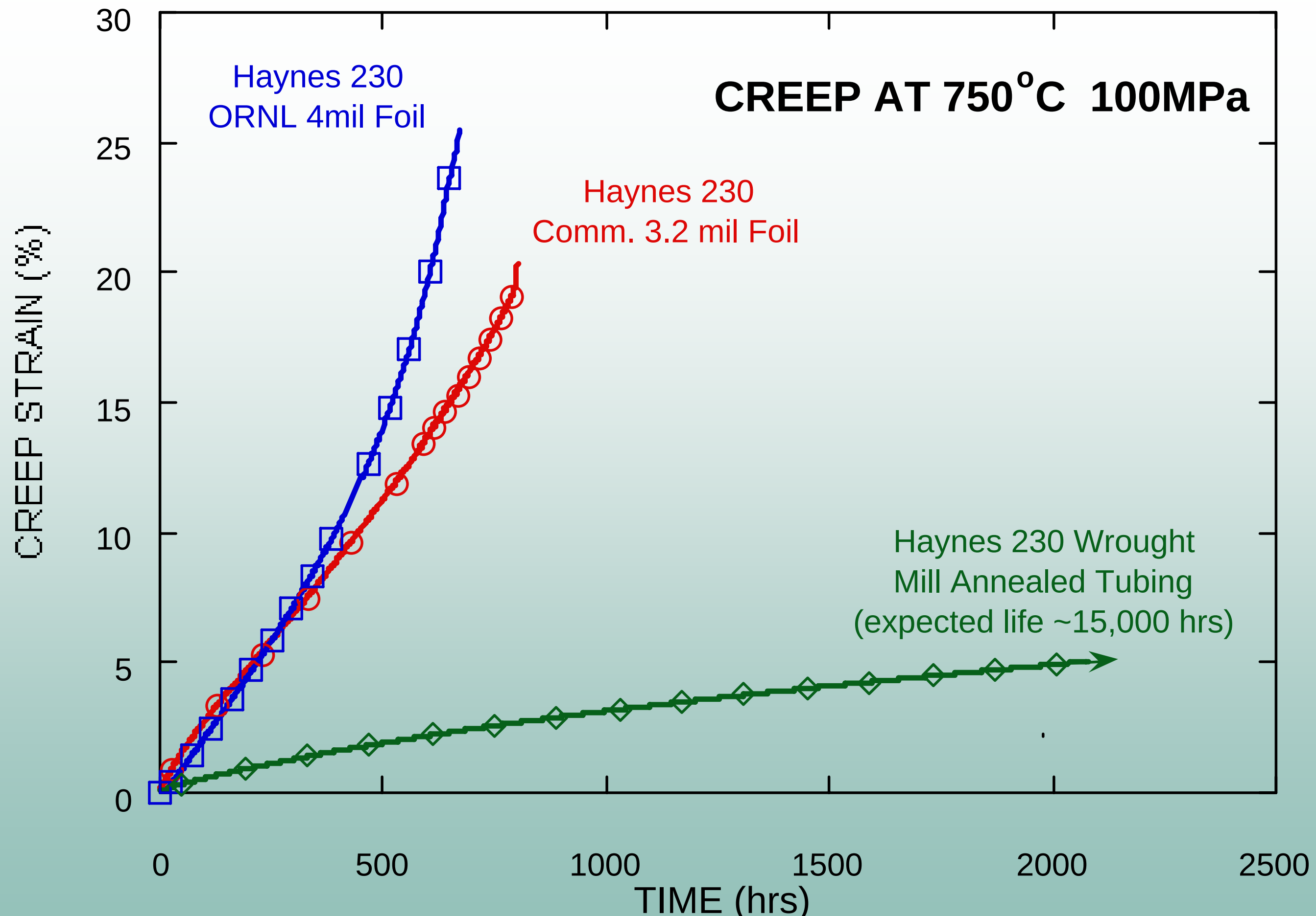
Alloy Selection for Recuperators is Complicated by Grain Size/Processing Effects That Make Foils and Sheets Much Weaker than Plate or Tubing



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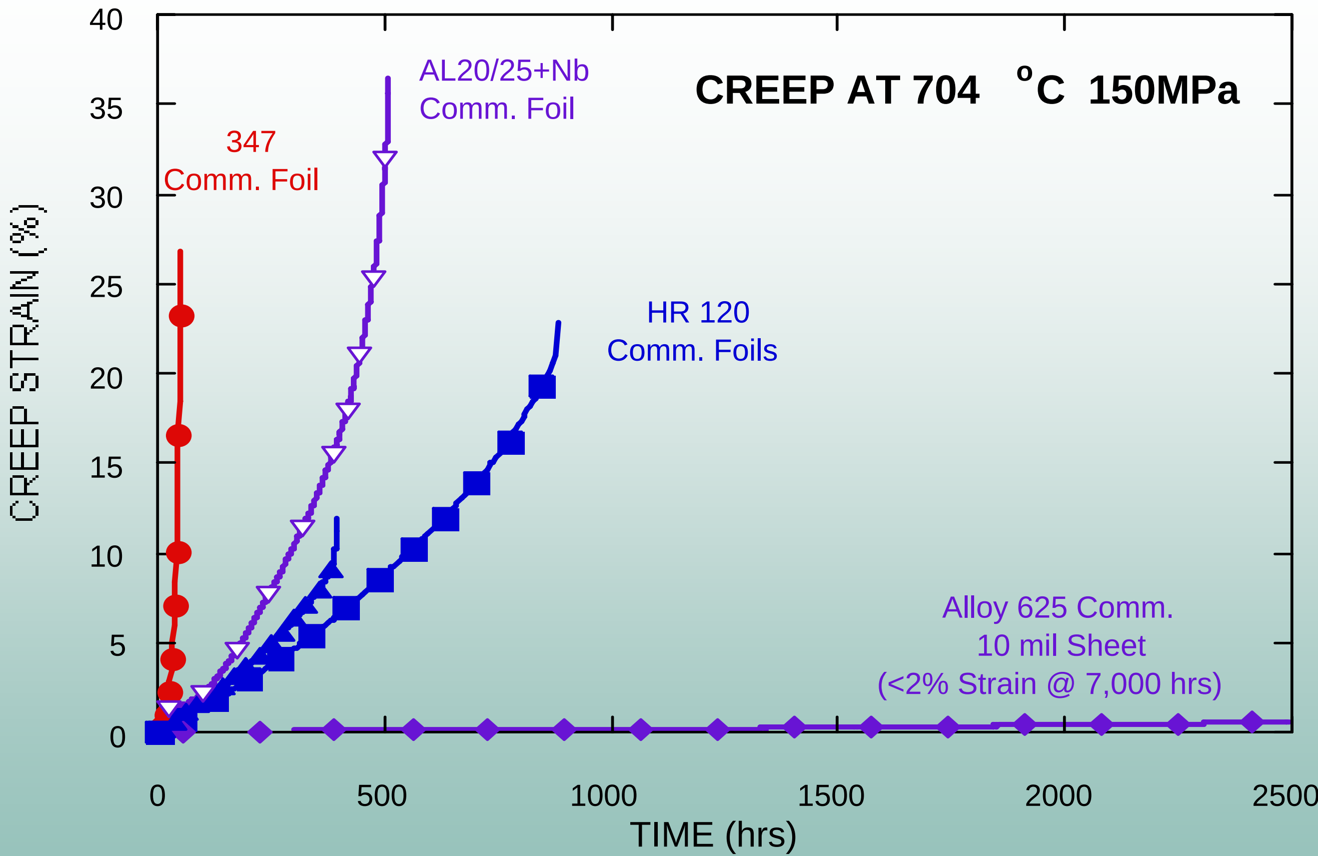

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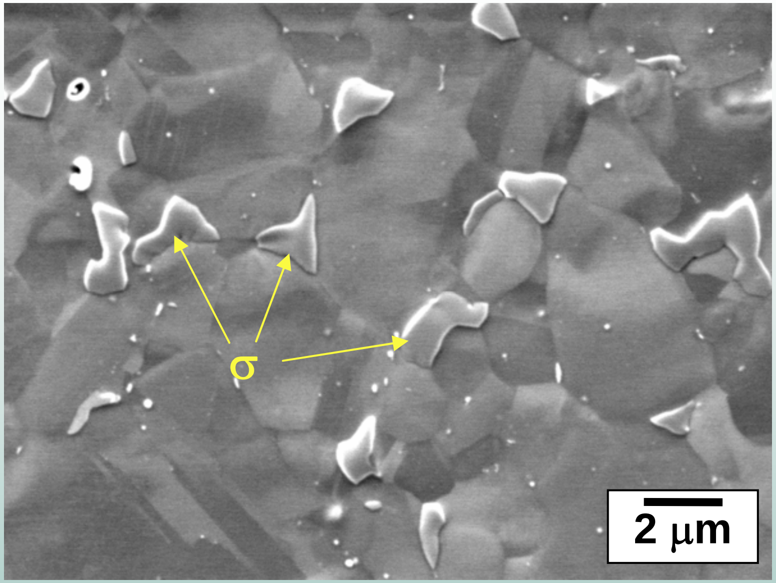
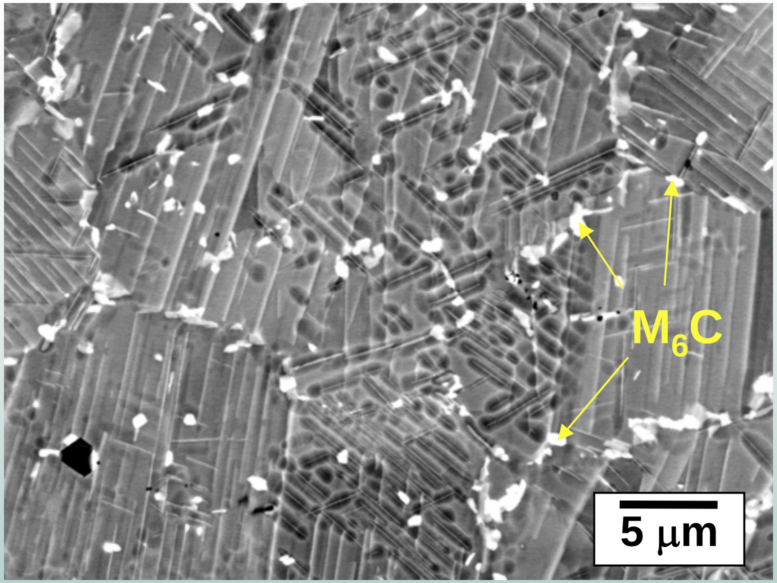
Alloy 625 Has Finer Precipitation of M_6C Instead of the FeCr σ-phase for Better Creep Resistance

SE SEM image

BSE SEM image



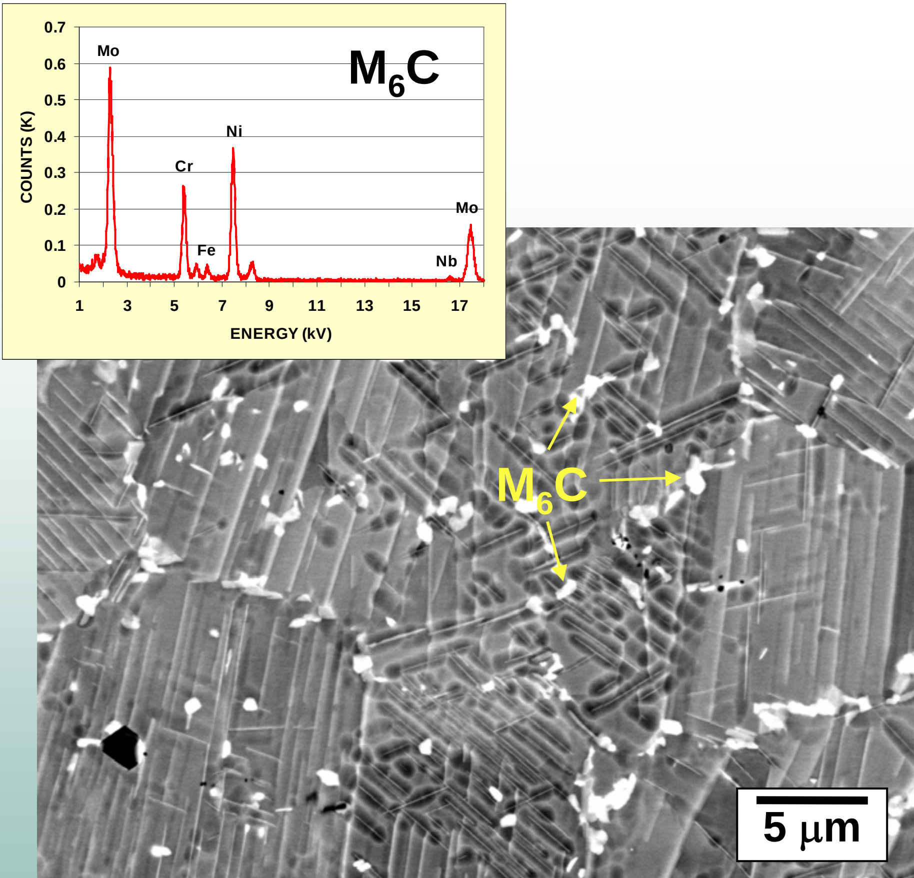
T347 crept 704ºC, 152 MPa t_r=51.4 h



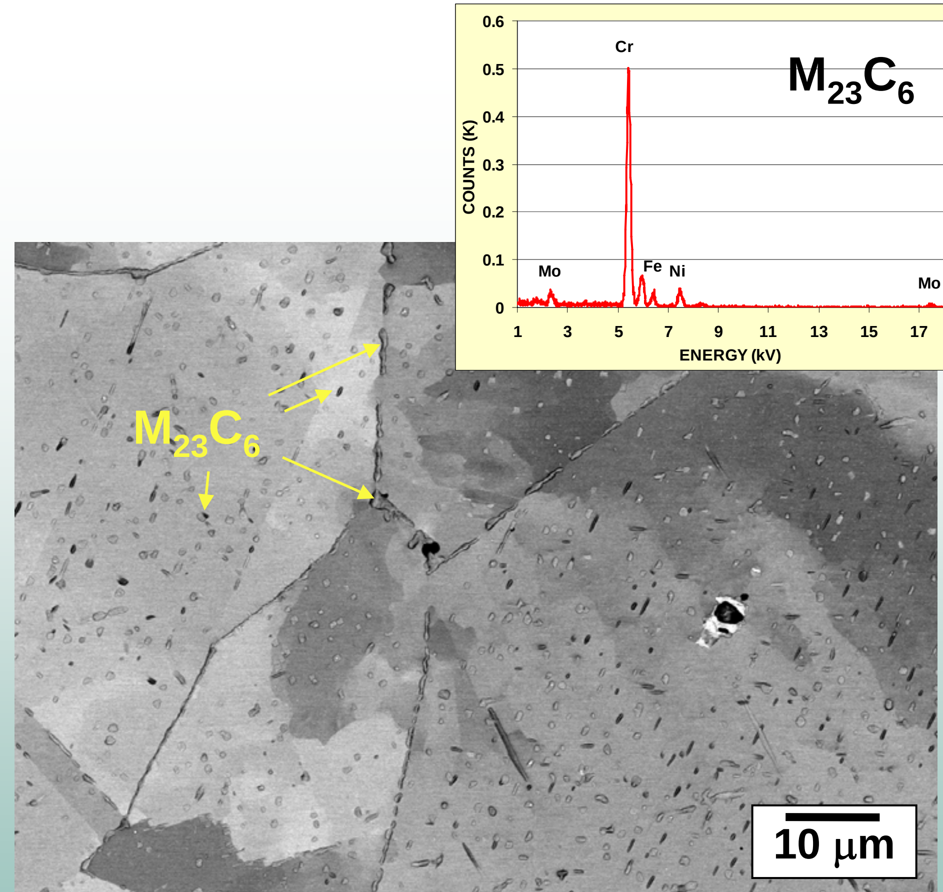
Alloy 625 crept 750ºC, 100 MPa t_r=4510 h

SEM images of electropolished TEM Disks, 4 mil foils

Grain Boundary Phases and Distributions Develop Differently in Alloy 625 and HR120 During Creep



Alloy 625 crept 750ºC, 100 MPa, t_r=4510 h

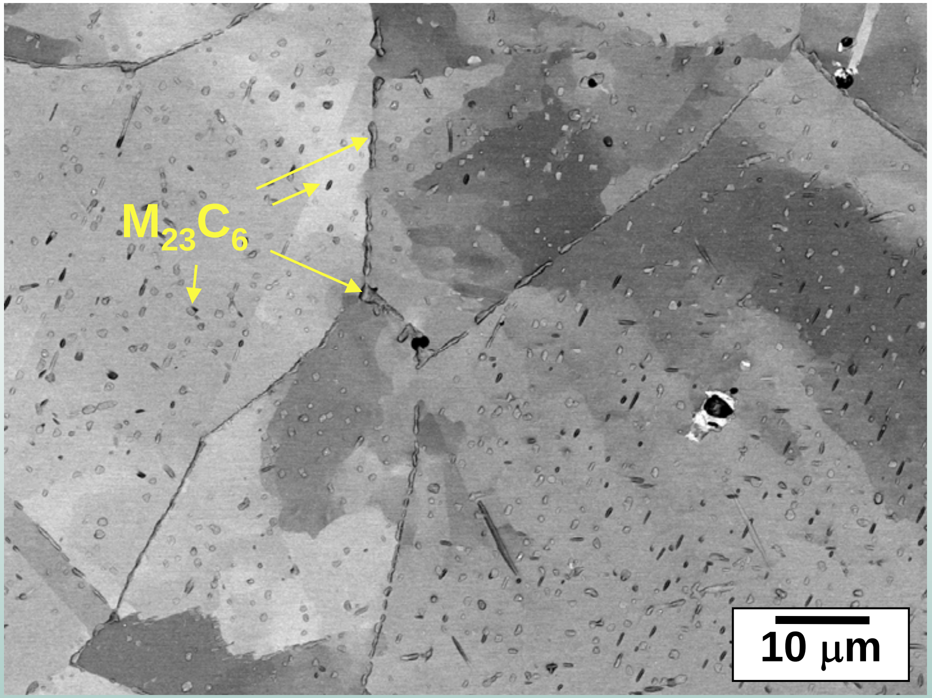


Alloy HR120 crept 750ºC, 100 MPa, t_r=3319 h

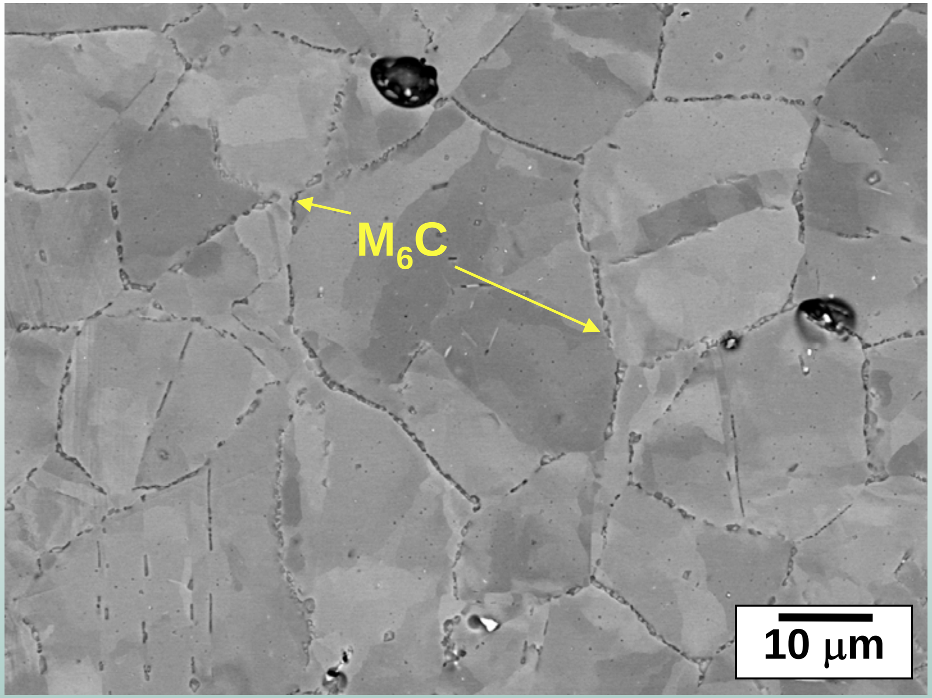
BSE SEM images

Subtle Difference in Grain Boundary and Matrix Carbides and Distributions Affect the Creep Differences Between NF709 and HR120

SEM BSE Images

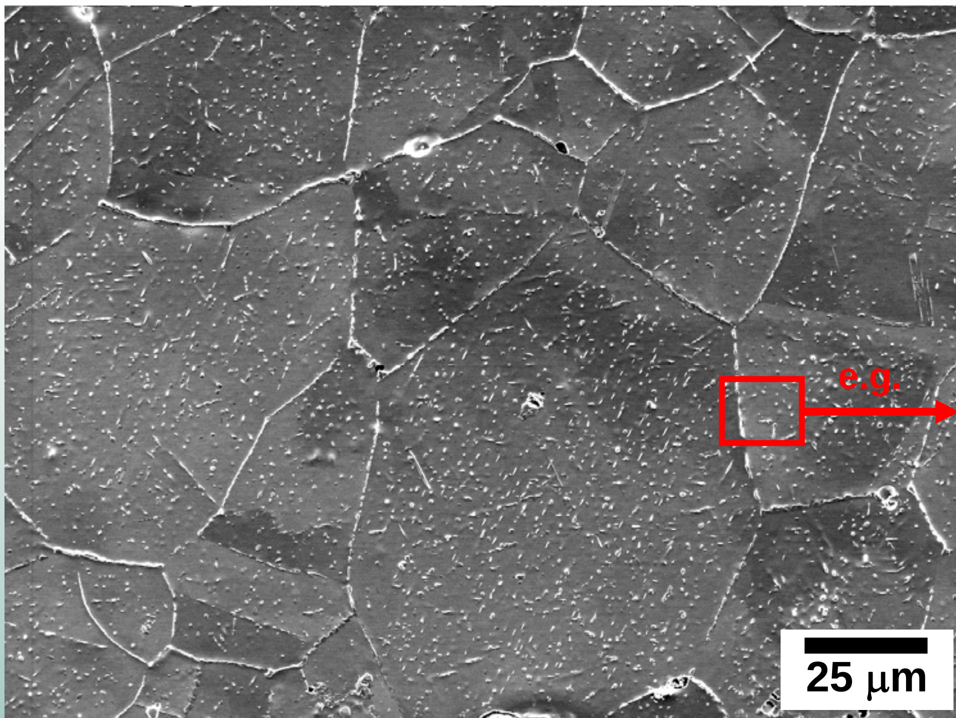


Alloy HR120 crept 750ºC, 100 MPa, t_r=3319 h

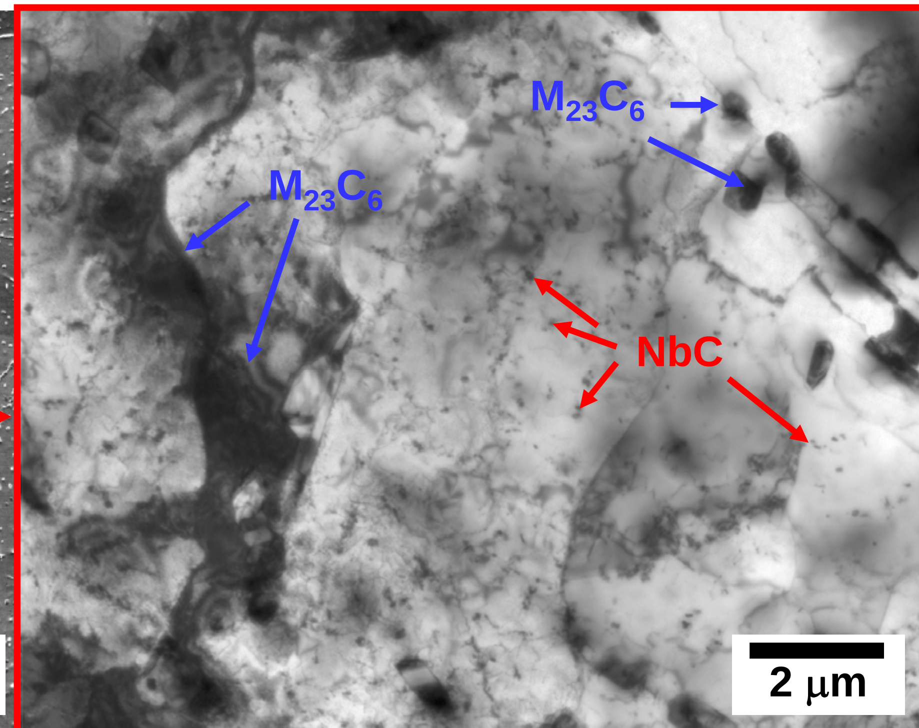


Alloy NF709 crept 750ºC, 100 MPa, t_r=5015 h

HR120 Foil Develops $M_{23}C_6$ Within Grains and Along Grain Boundaries and Finely Dispersed NbC Within the Grains During Creep at 750°C



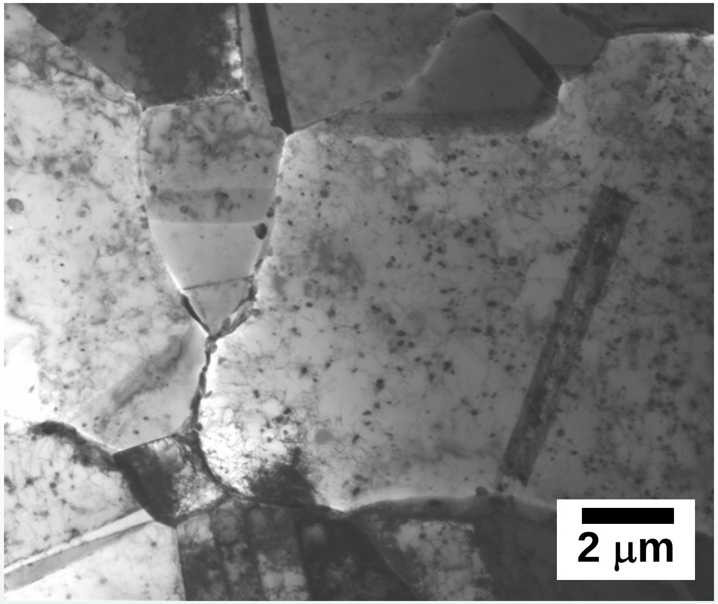
SE SEM Image

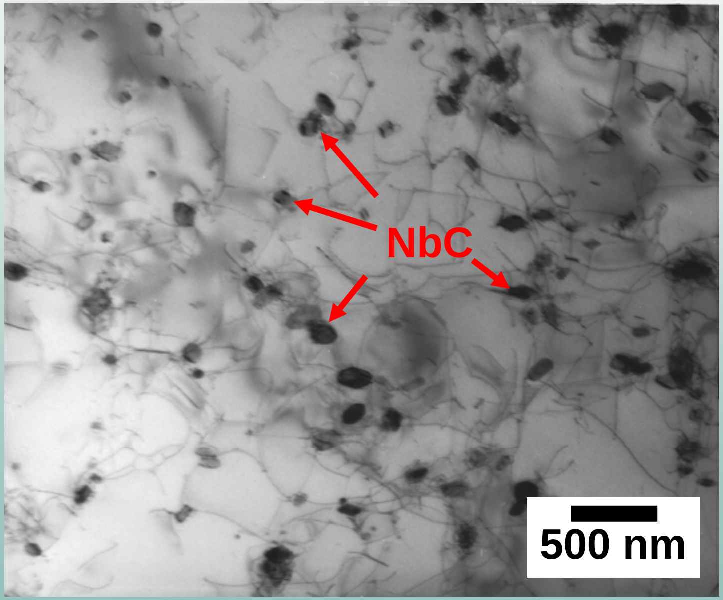


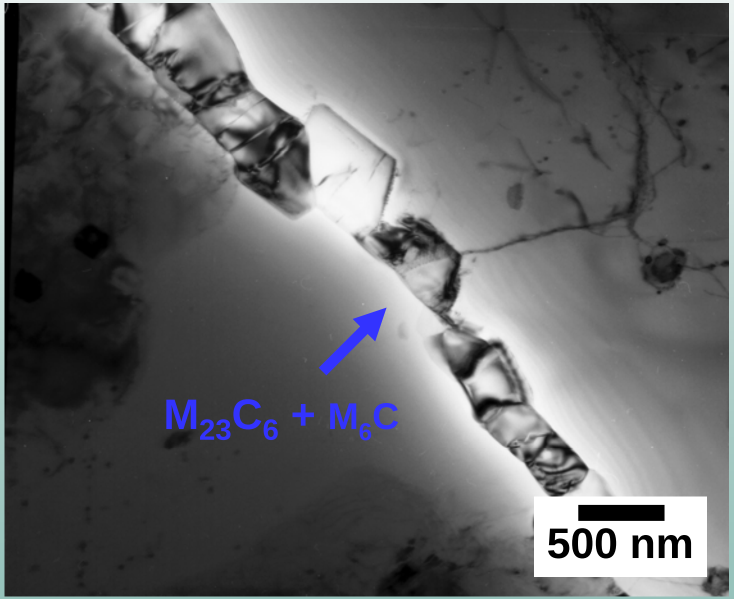
TEM Image

Creep Tested 750°C 100mPa; t_r = 3320 h

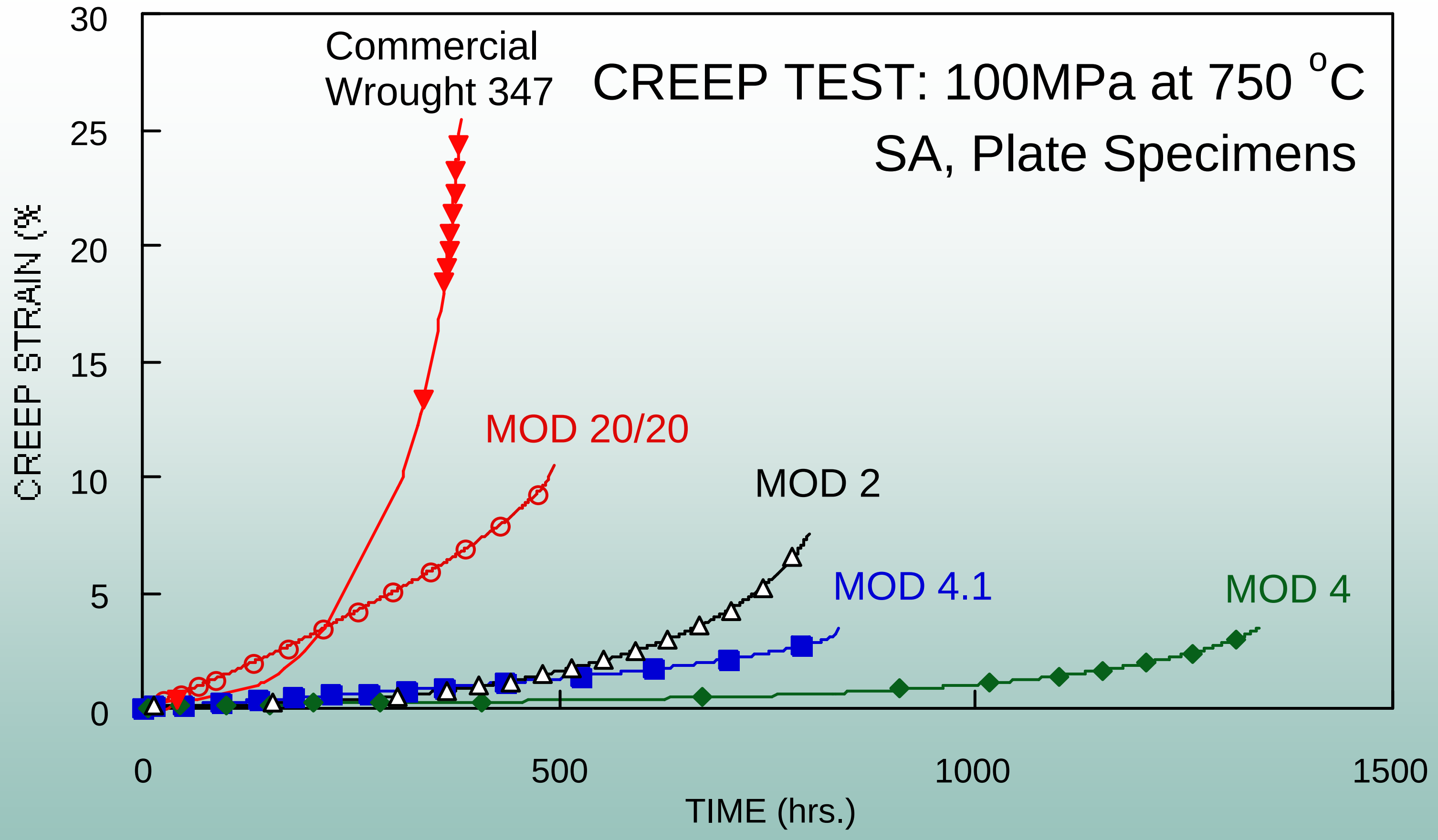
NF709 Foil Contains Finely Dispersed NbC Within the Grains and $M_{23}C_6$ and M_6C Along Grain Boundaries After Creep at 750°C/100 MPa for 5015h







ORNL has developed new, modified 347 stainless steels with much better creep resistance at 750ºC



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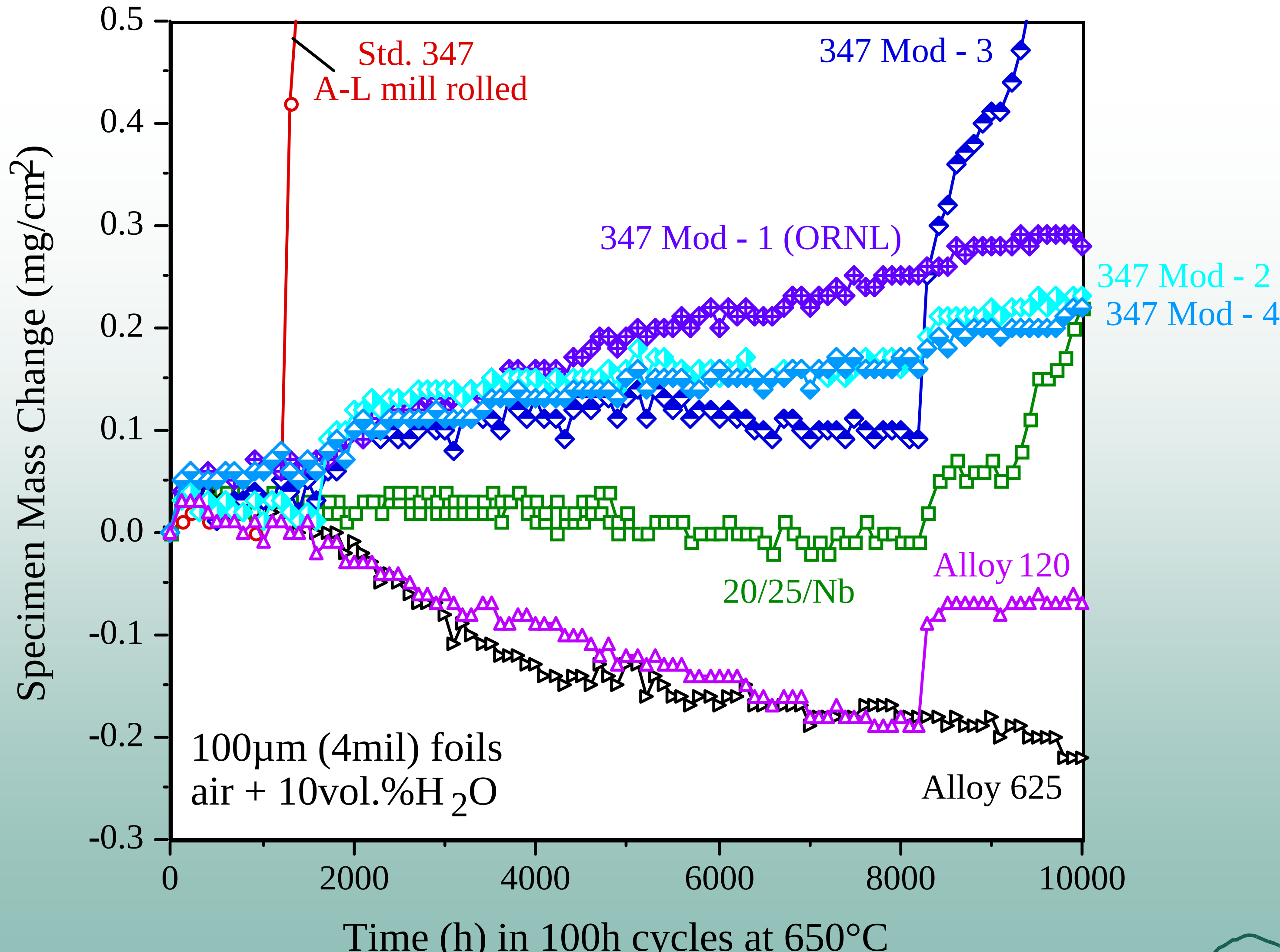
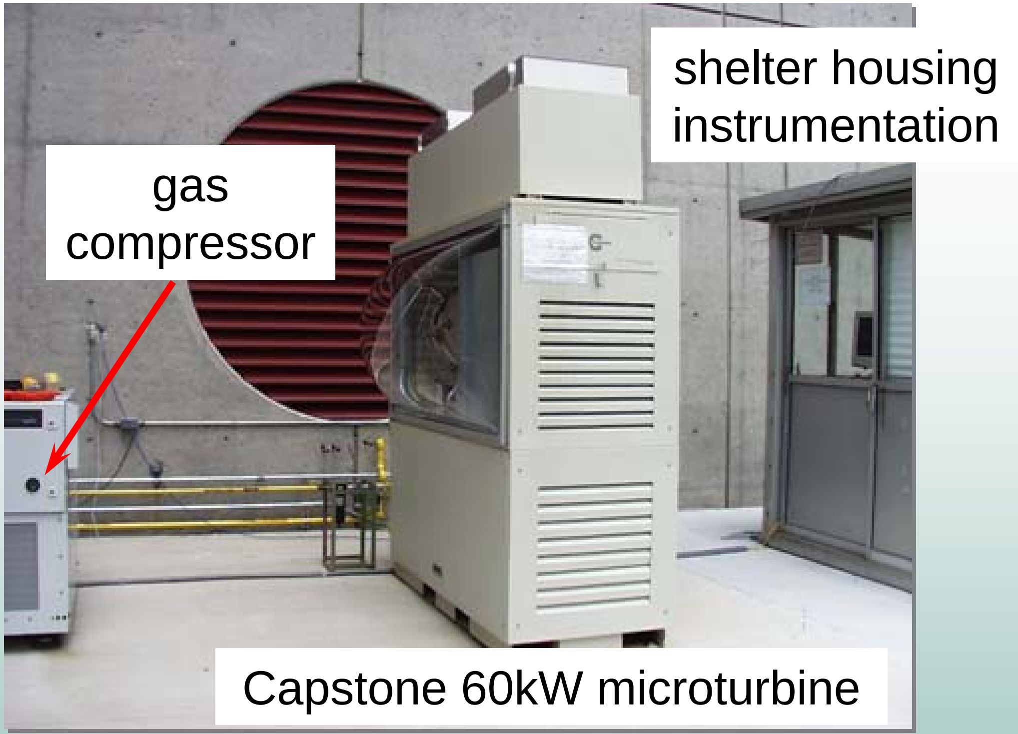
Several more heat resistant alloy also show much better resistant to moisture enhanced oxidation than 347 steel

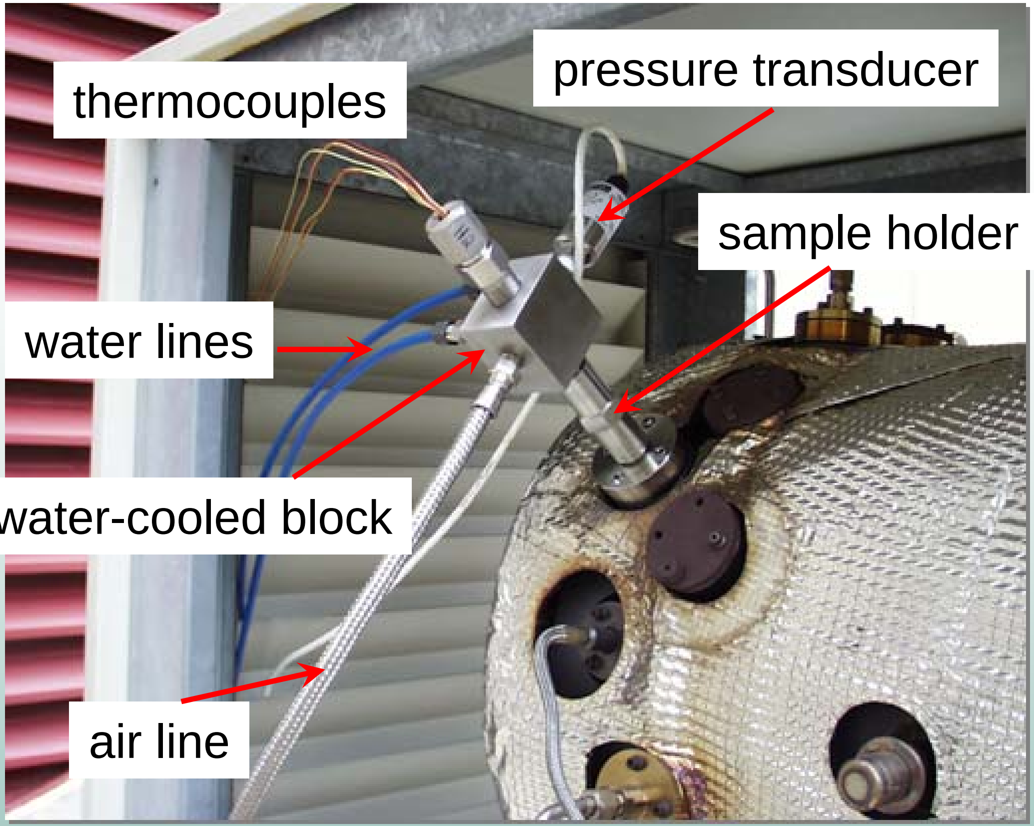


Microturbine Test Facility

As part of the Advanced Materials for Recuperators Program, ORNL established a microturbine test facility to screen and evaluate candidate materials for advanced microturbine recuperators



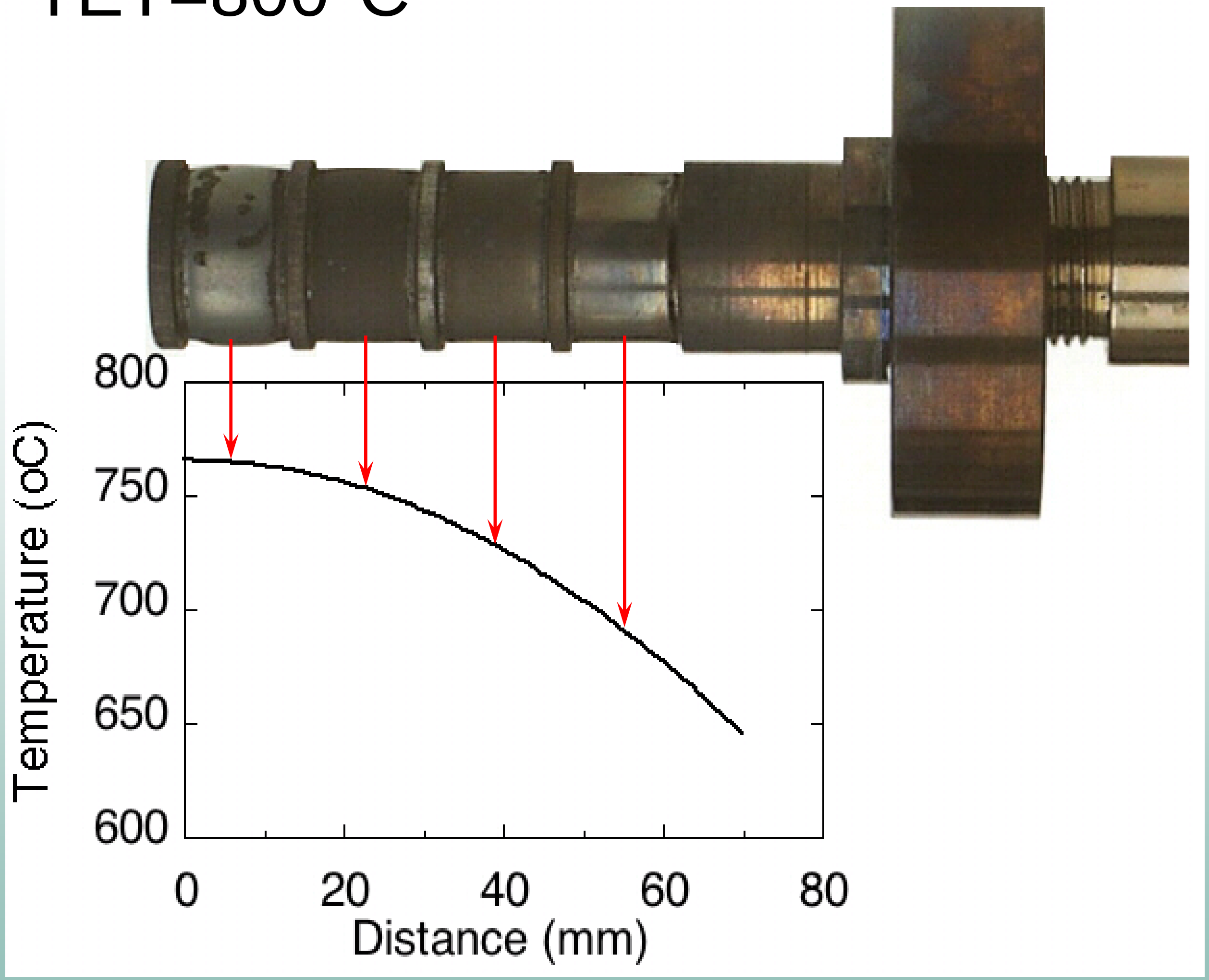
ORNL's Microturbine Test Facility (cont.)



- Modified Capstone C60 microturbine
- Higher TET (850°C)
- Placement of test specimens at the entrance of recuperator.

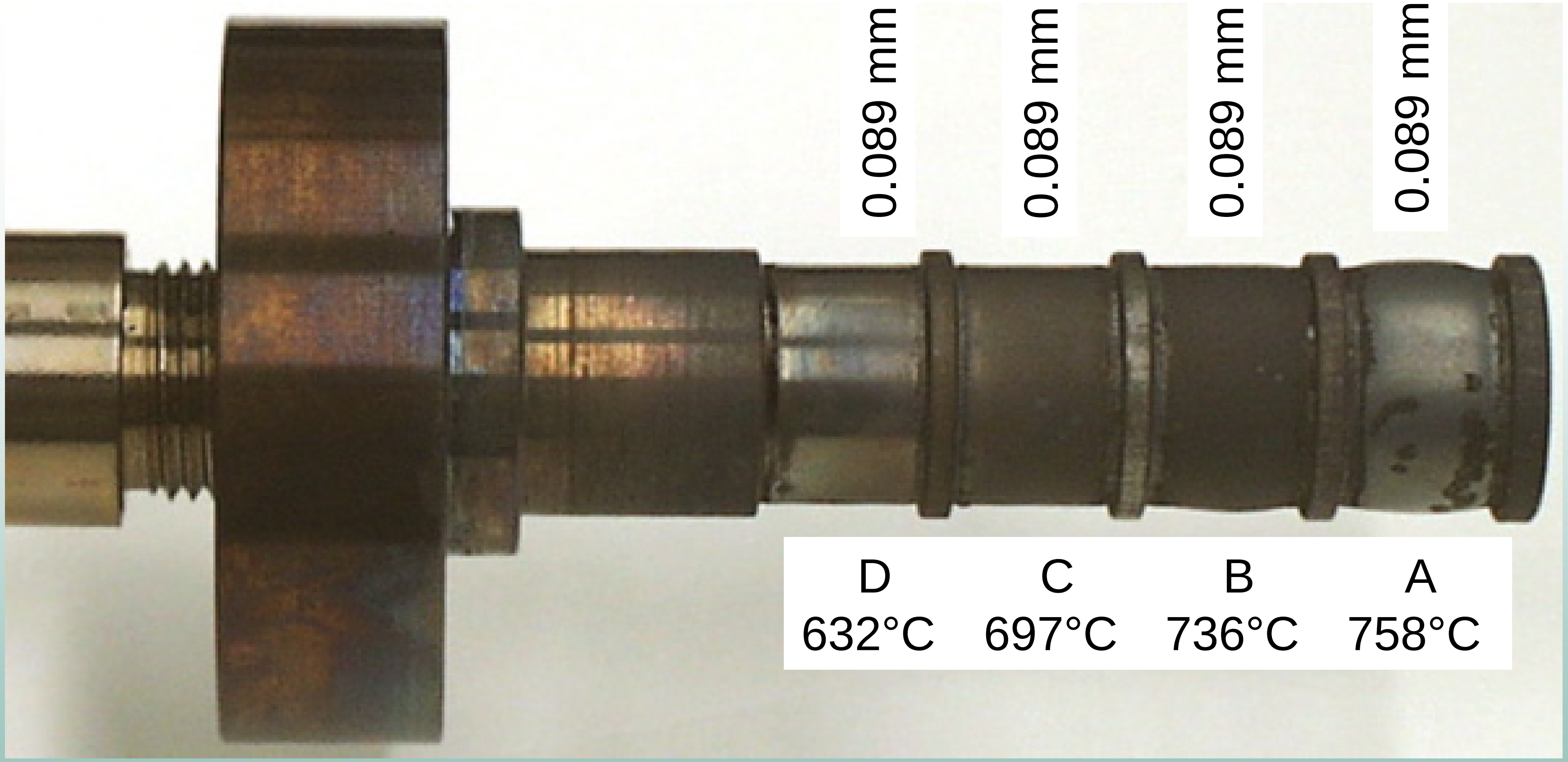
Temperature distribution along sample holder

TET=800°C

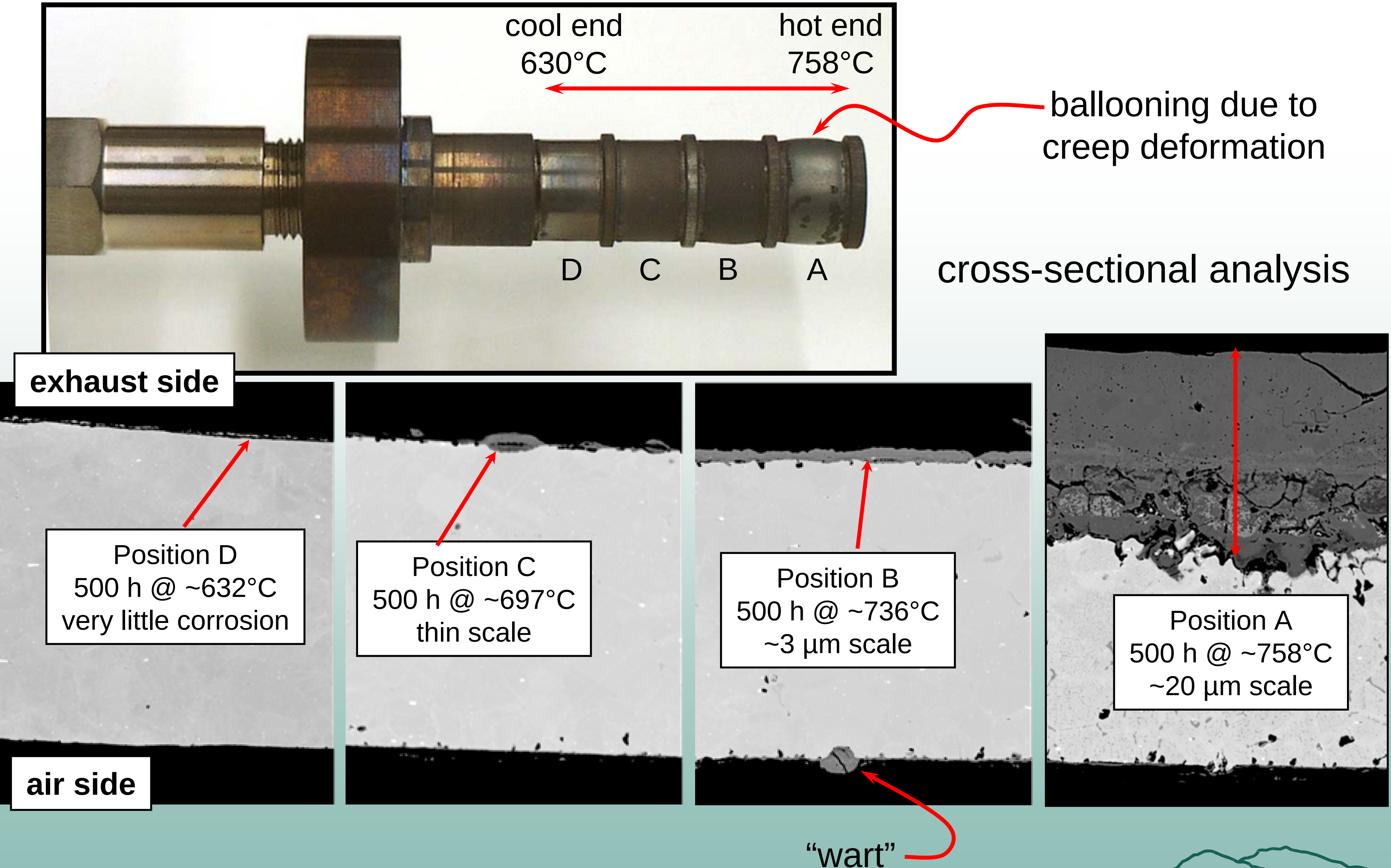


347-stainless steel after 500-hr exposure (TET=800°C)

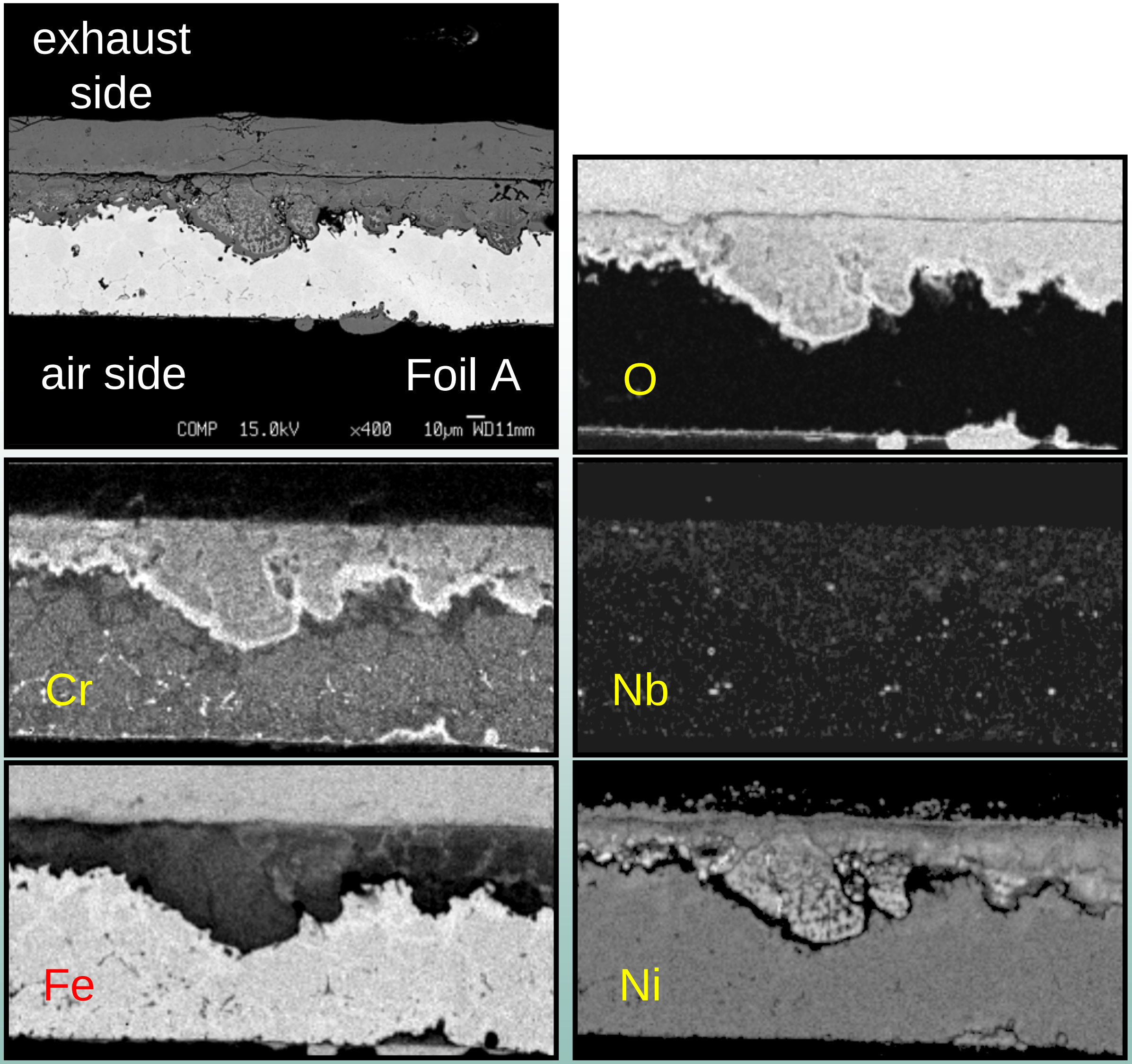
60 psi internal pressure -> 50 MPa hoop stress



347-stainless steel after 500-hr exposure



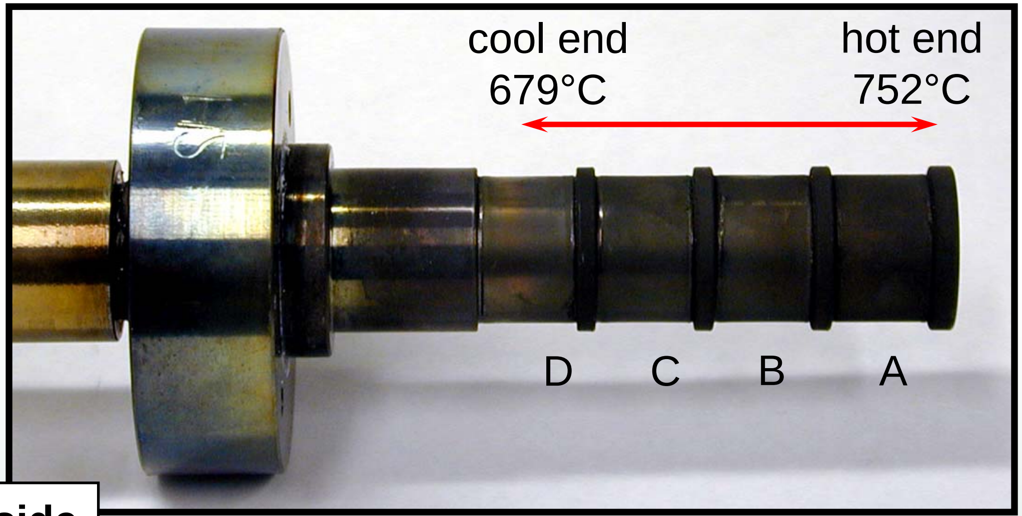
347-stainless steel after 500-hr exposure



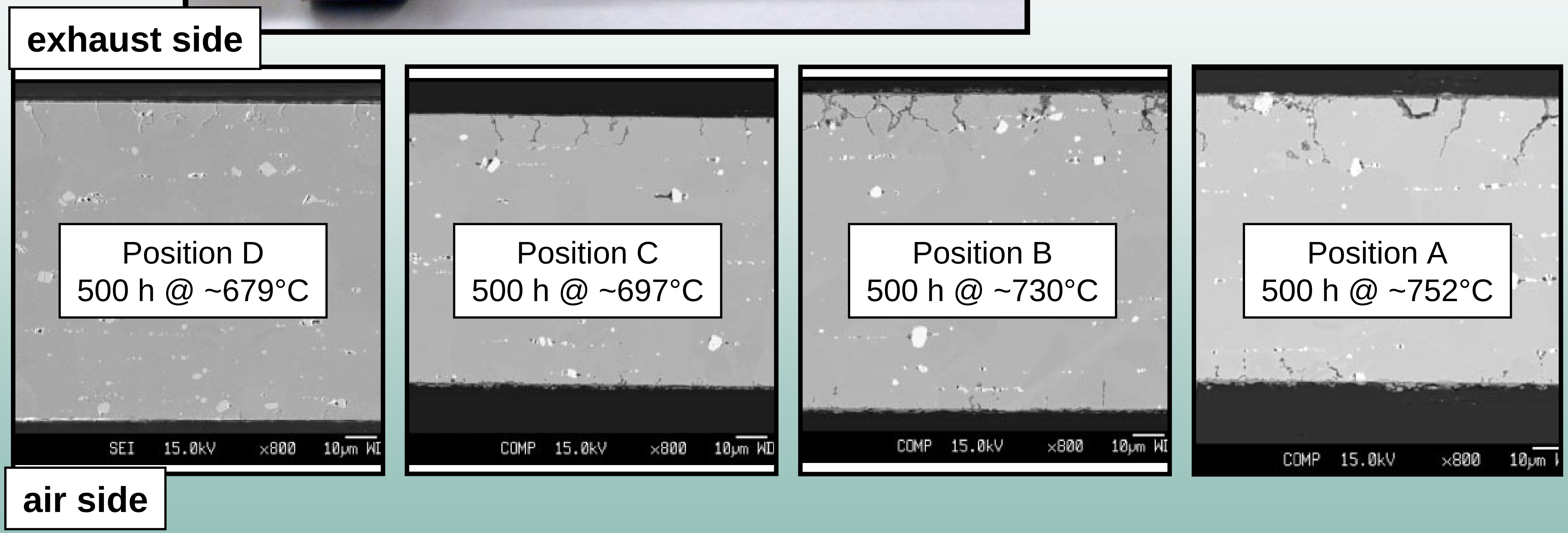
Foil exposed at 758°C

- Multilayered oxide scale:
  - Ni-Cr-O
  - Fe-O
- Depletion of Cr at GBs
- Carbide formation

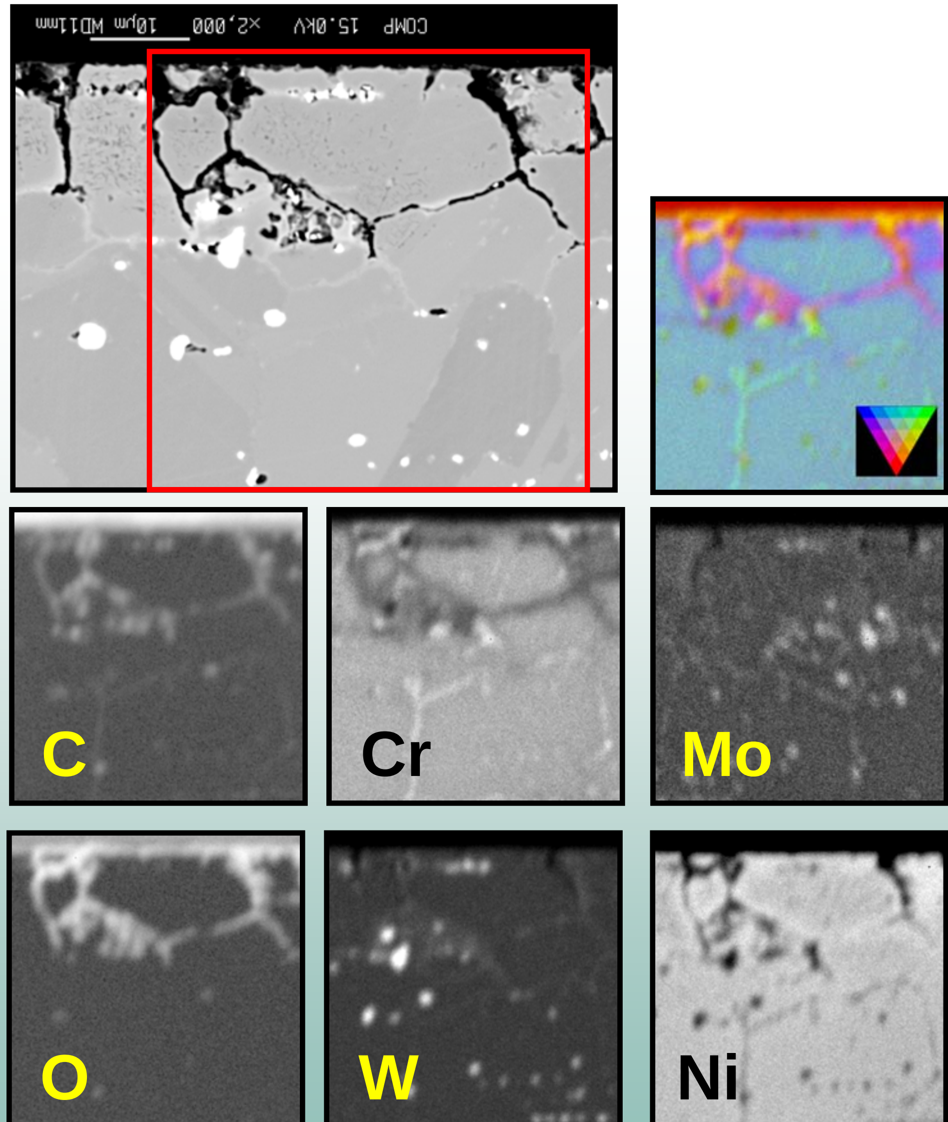
HR230® after 500-hr exposure (TET=800°C)



cross-sectional analysis



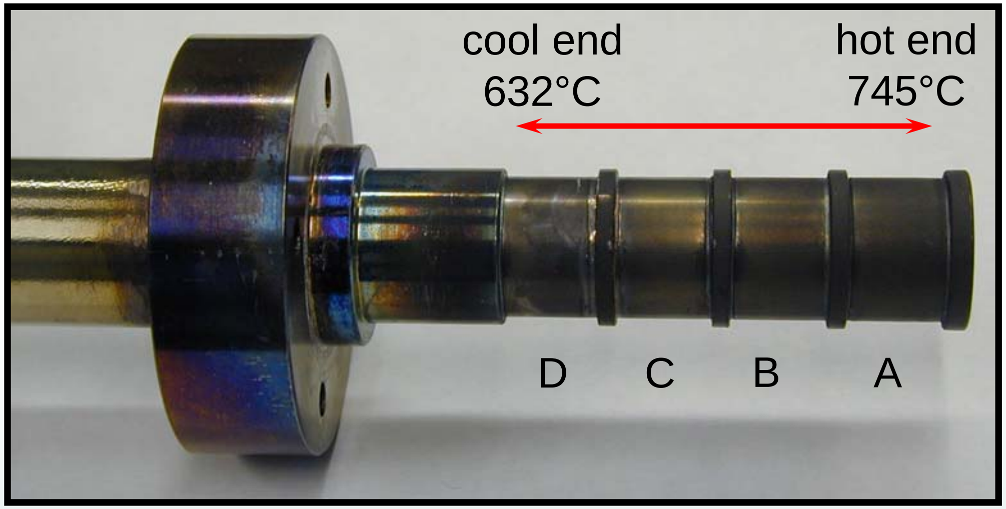
HR230® after 500-hr exposure (TET=800°C)



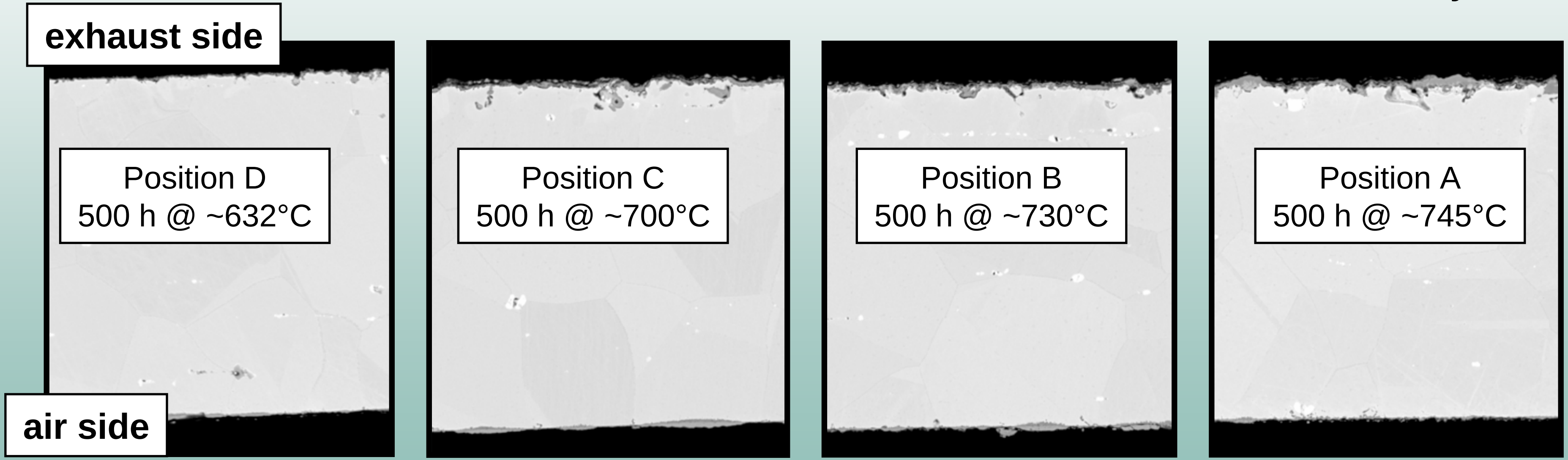
Foil exposed at 752°C

- Limited corrosion products found on surface
- Significant cracking along grain boundaries
- Grain boundaries near surface are poor in Cr but rich in W and C.

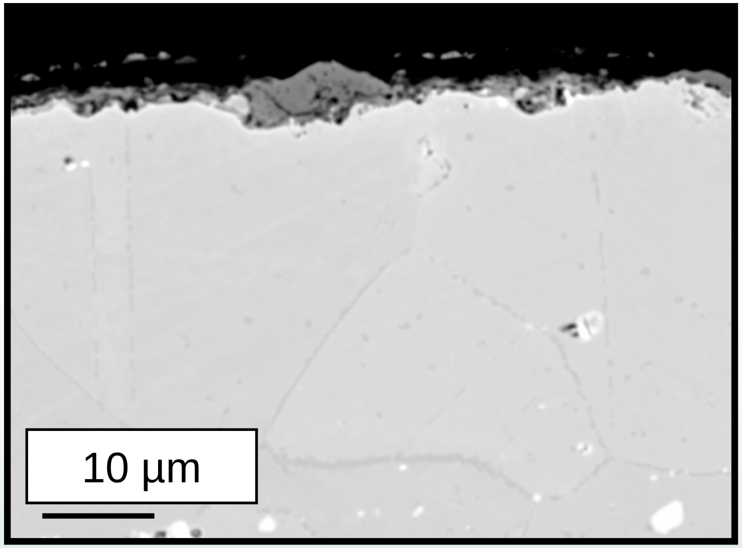
HR120® after 500-hr exposure (TET=800°C)



cross-sectional analysis

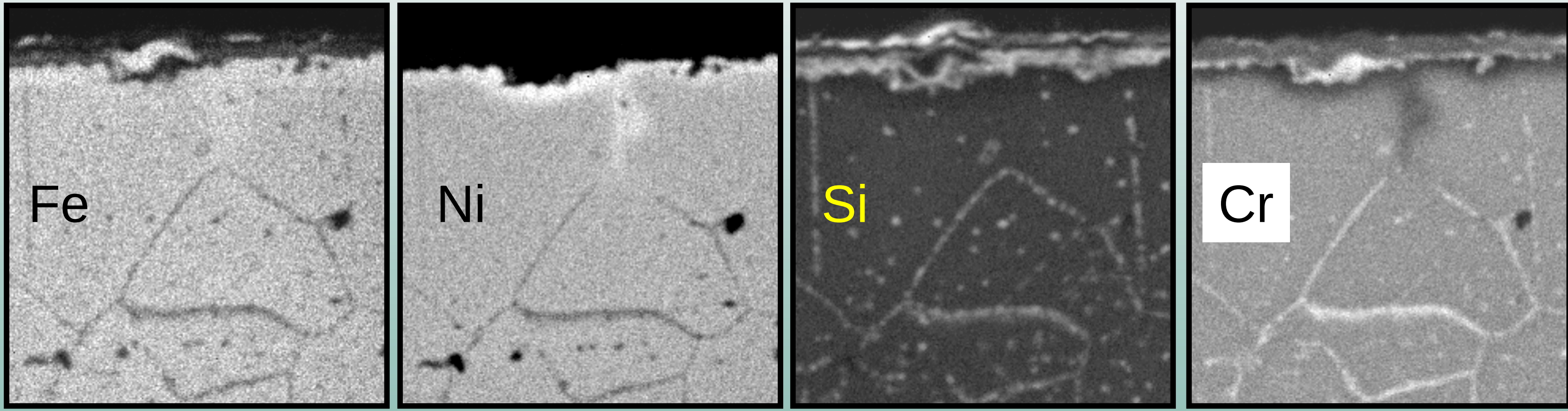


HR120® after 500-hr exposure (TET=800°C)



Foil exposed at 745°C

- Limited corrosion (oxides of Cr, Si and and Fe)
- Grain boundaries near surface are poor in Cr but rich in Ni



Summary

- ORNL has characterized commercial foils and sheet of stainless steels and alloys used to make recuperator air cells
- HR120 and alloy 625 (and the new AL20-25+Nb) are all commercial high-performance alternatives to 347 stainless steel at 650-750^{o}C
- ORNL is working with OEMs to make recuperators from advanced alloys that are also cost effective
- ORNL is extending characterization of commercial sheet and foil alloys to test their capabilities at 800^{o}C and above.