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

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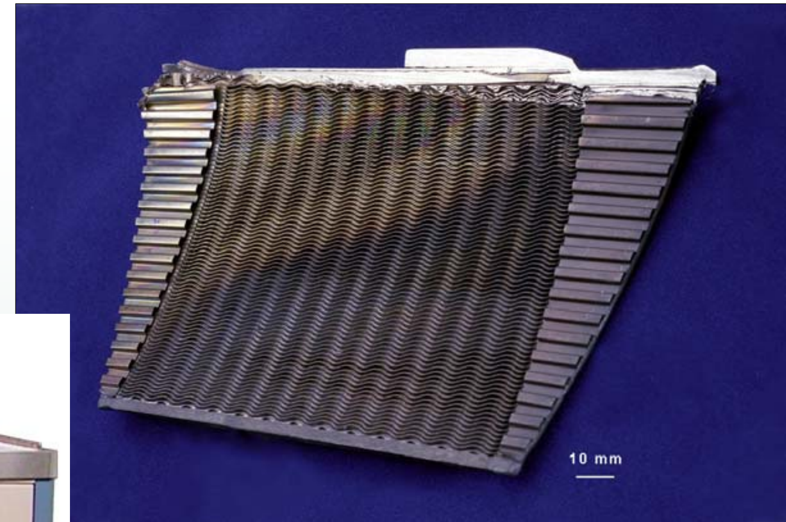
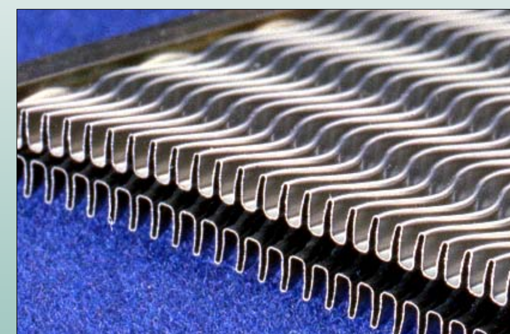
Recuperators Are Compact Heat Exchanges that Boost the Efficiency of Microturbines

Capstone 200 kW Microturbine





Primary Surface Recuperator (PSR), annular configuration

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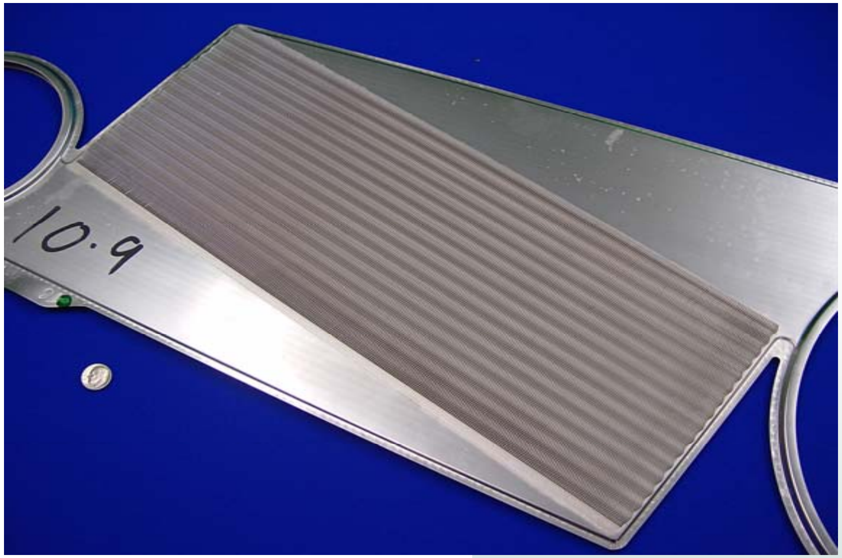
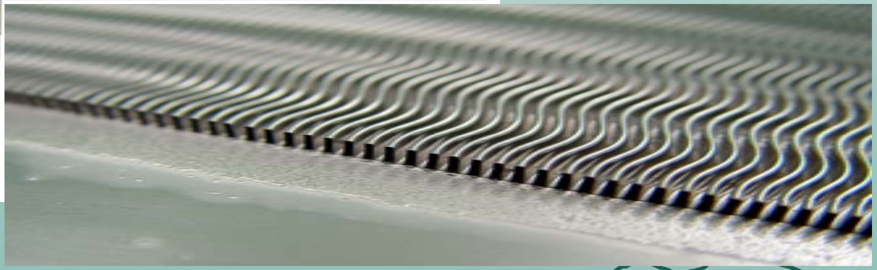
Brazed Plate and Fin Recuperator (PFR), vertical stack configuration



Ingersoll Rand
Energy Systems



250 kW Microturbine

Background

Research by ORNL and others has shown that temperature and water vapor enhanced oxidation are the primary factors affecting degradation, with stress and creep becoming factors at higher temperatures and longer times

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

Background

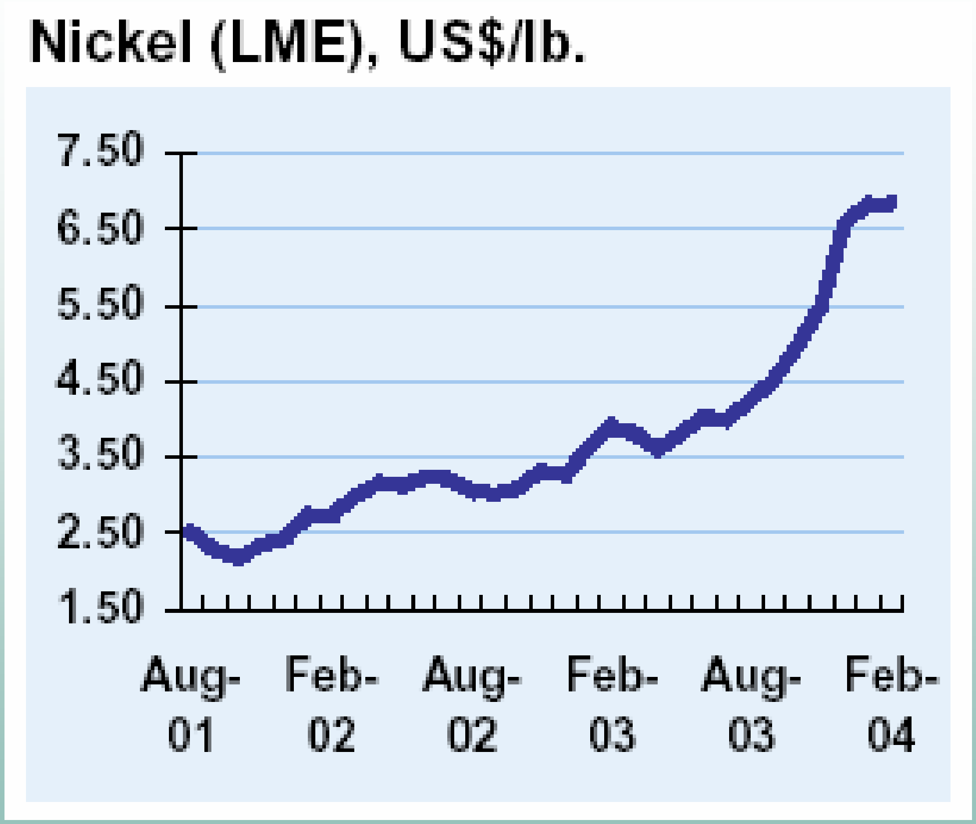
From 2000 to today, research at ORNL supports the needs of the DOE Advanced Microturbines Program, with efficiency goals of >40%

- Interactions and collaborative work with microtubrine OEMs, including Capstone Turbines, Ingersoll Rand Energy Systems, and others
- Interactions with foil and sheet producers
- 2002-2003, ORNL and Allegheny Ludlum collaborated to develop commercial sheet and foils of AL347HP^{TM}, with improved creep resistance based on controlled grain size
- 2004 – present, ORNL and Allegheny Ludlum are collaborating to develop commercial sheets and foils of the new AL20-25+Nb with its best creep resistance

In 2002-2003, ORNL Began Evaluating Commercial Foils Use in Recuperators, Supplier by Either Microturbine OEMs or Foil Producers (Alloy Compositions (wt.%))

- 347 steel – Fe -18Cr-9.5Ni-1.5Mn-0.25Mo-0.04C-0.63Nb
- HR120 – Fe -25Cr-33Ni-1Mn-1Mo-0.05C-0.7Nb-0.2N
- AL20-25+Nb – 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

Rising costs of Ni, Mo and now W are making high performance heat-resistant alloys more expensive



347 =x

HR120 = 3.5x

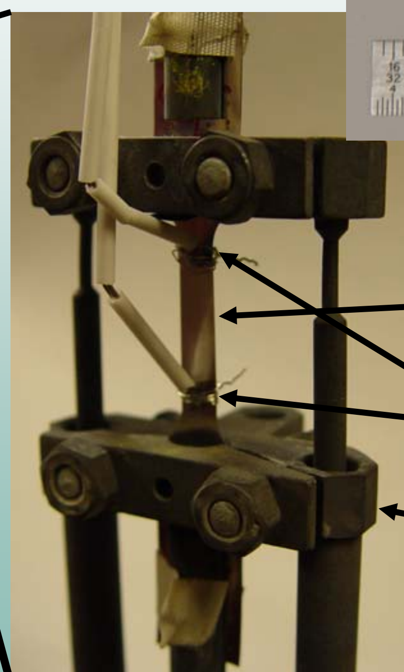
HR230 = 7x

625 = 3.5-4x

AL20-25+Nb <2x(?)

Since about 1998, ORNL has refined and optimized equipment and techniques for creep testing of thin foils, which were initially developed by Montague at Solar Turbines

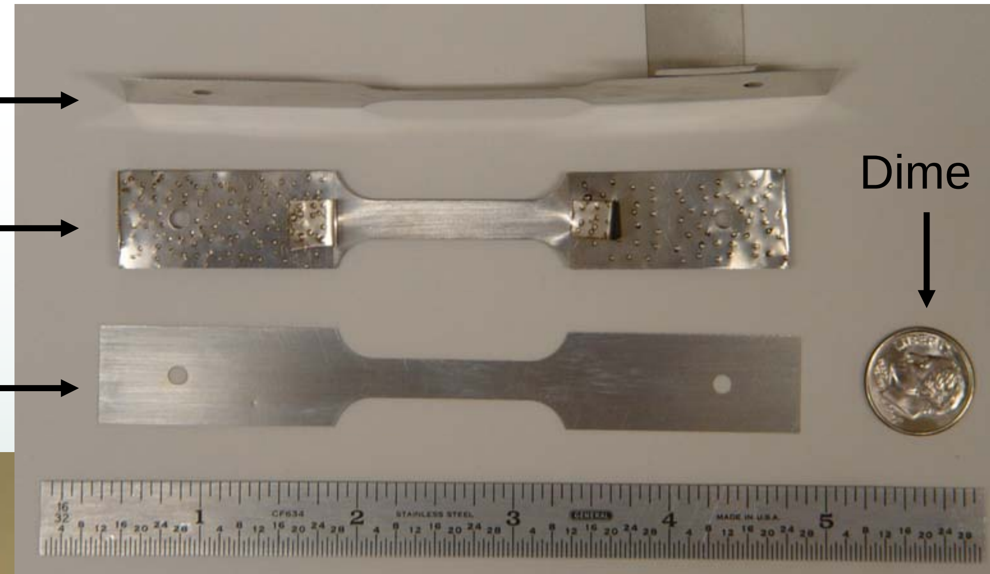
LVDTs for Continuous Monitoring of Creep Strain



Specimen

Thermocouples

Extensometer



4mil Thick Foil

Specimen w/Tabs

Specimen

Dime

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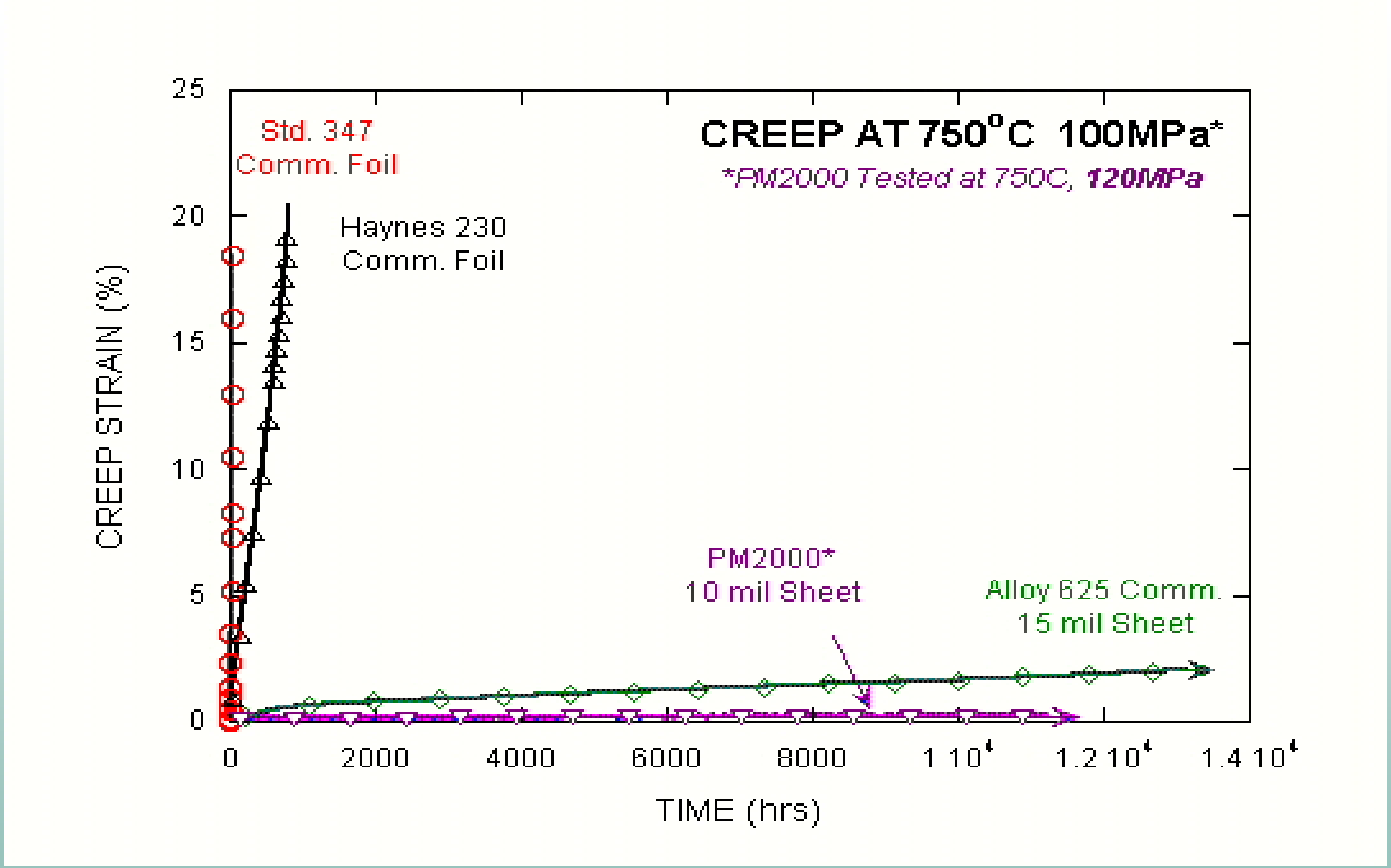
At 750°C, sheets of alloy 625 show very good creep resistance, much better than standard 347 steel



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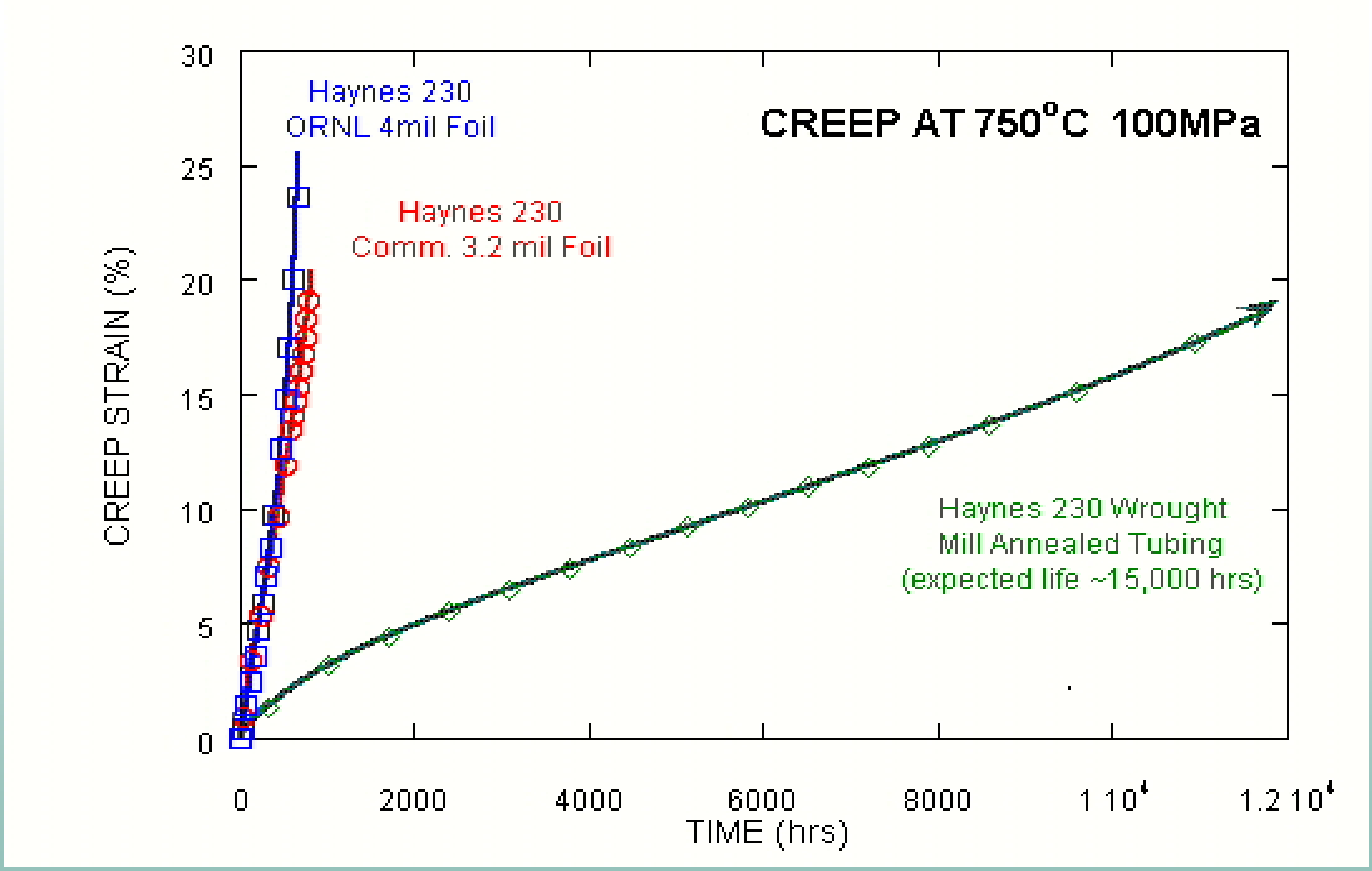
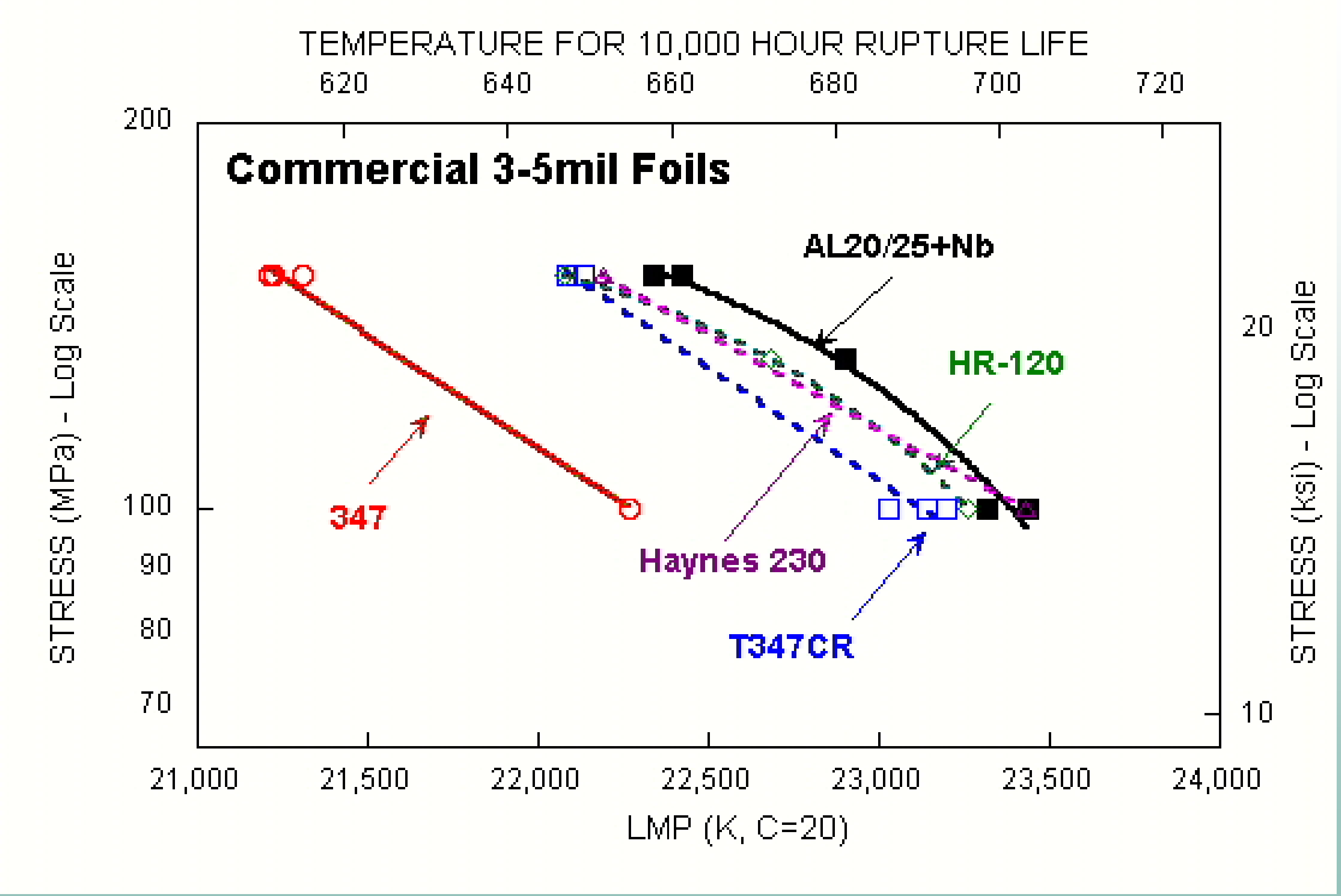
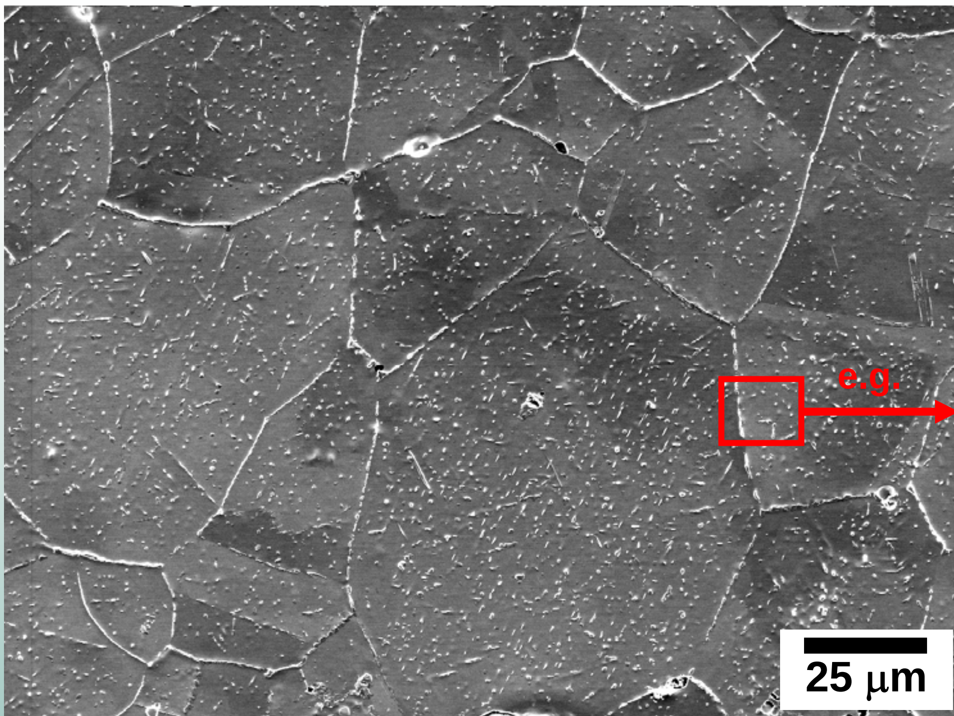
HR230 is very sensitive to grain size, which makes the creep resistance of foils much less than thicker plates or tubes



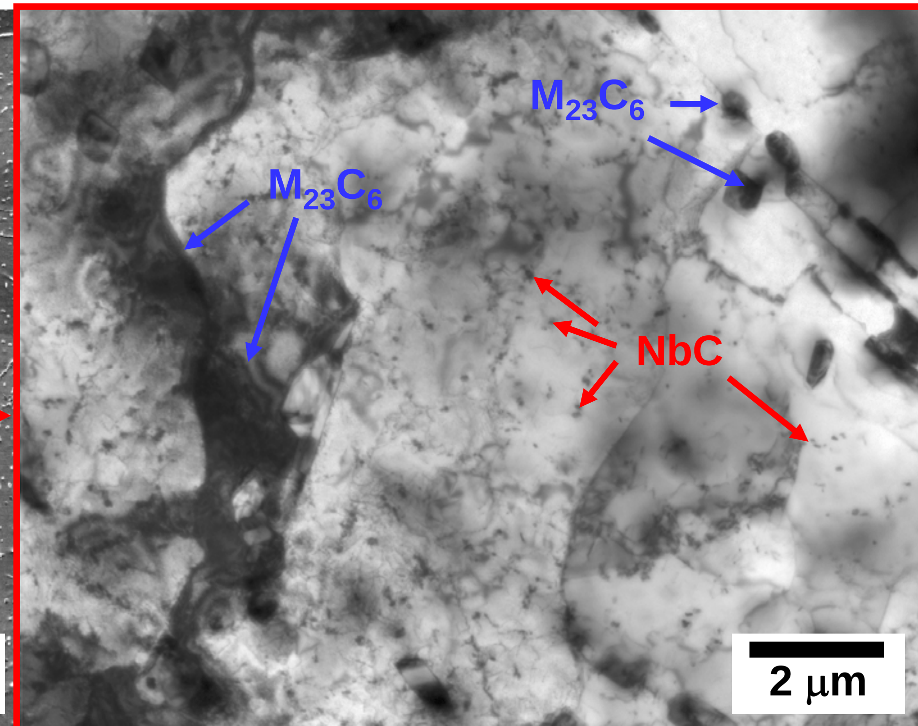
At 700-750ºC, foils of 347CR (AL347HP), HR120, and the new AL20-25+Nb, all have much better creep resistance due to grain size and fine NbC strengthening compare to standard 347 stainless steel



Good creep resistance of HR120 and AL20-25+Nb Foils are due to stable grain boundary carbides and fine dispersions of NbC within the grains during creep at 750°C



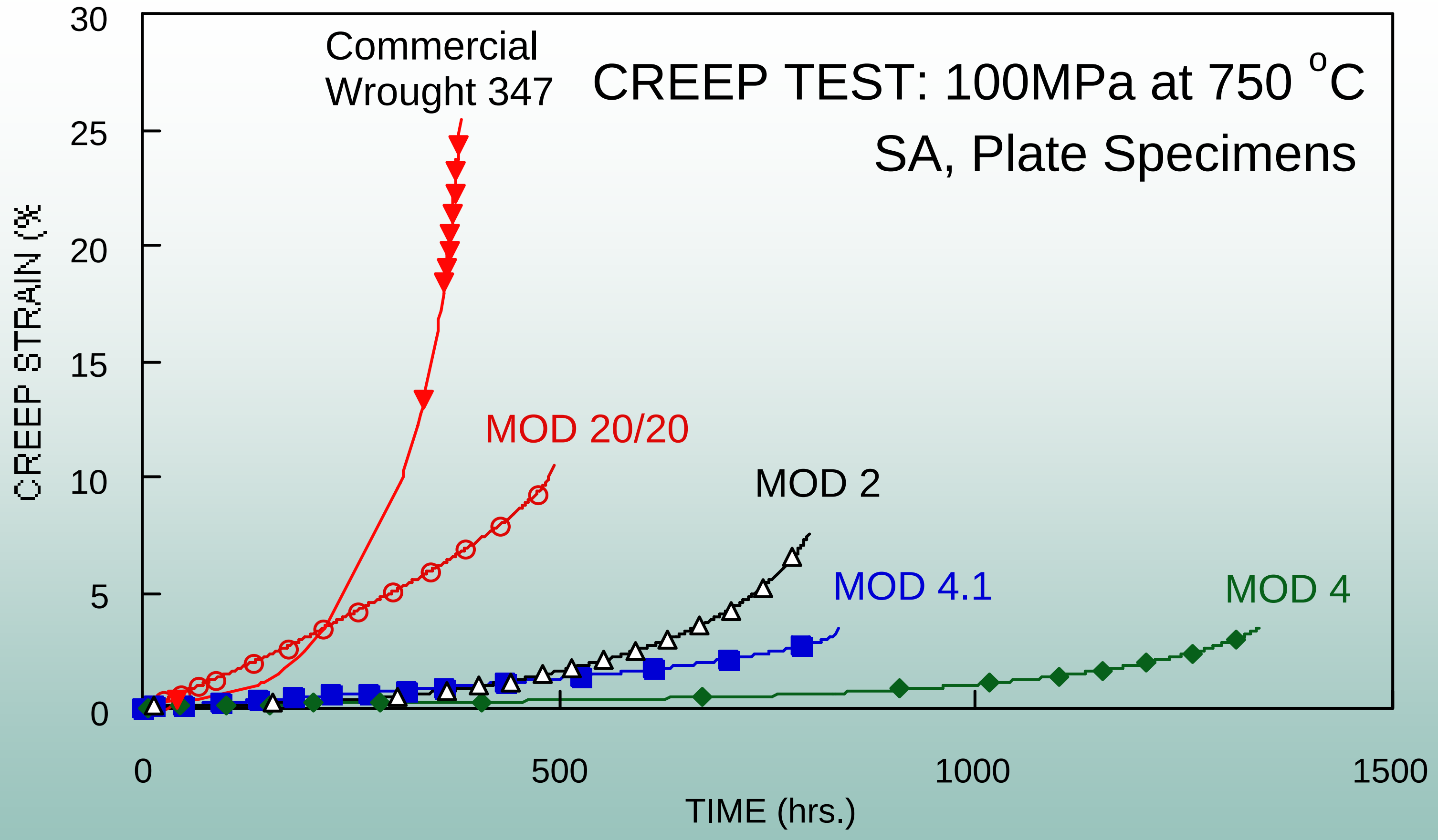
SE SEM Image



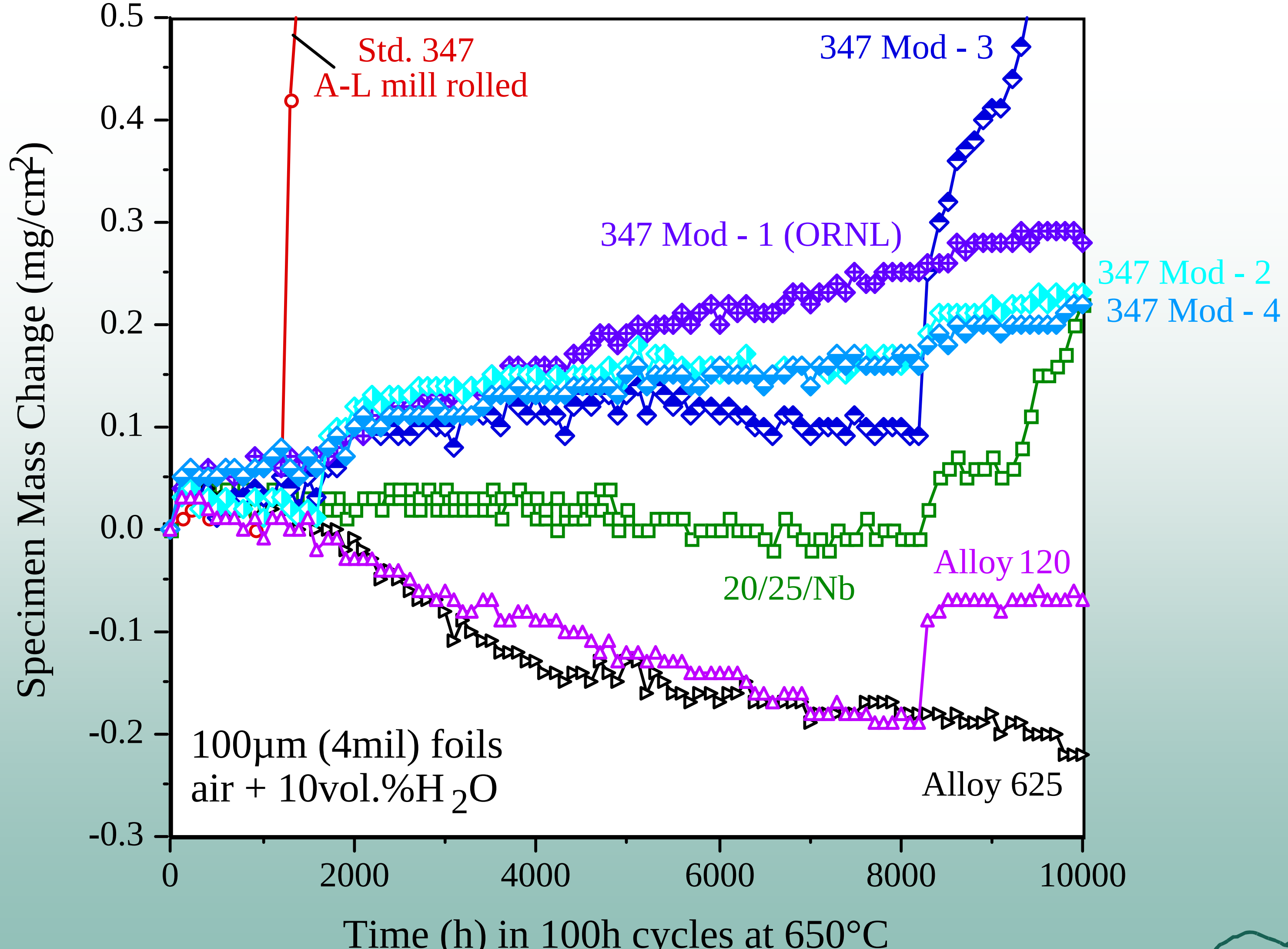
TEM Image

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

ORNL has also developed some new, modified 347 stainless steels which also have much better creep resistance at 750ºC



Heat resistant alloys like 625, HR120, and 20-25+Nb with more Cr also have much better resistant to moisture enhanced oxidation than 347 steel



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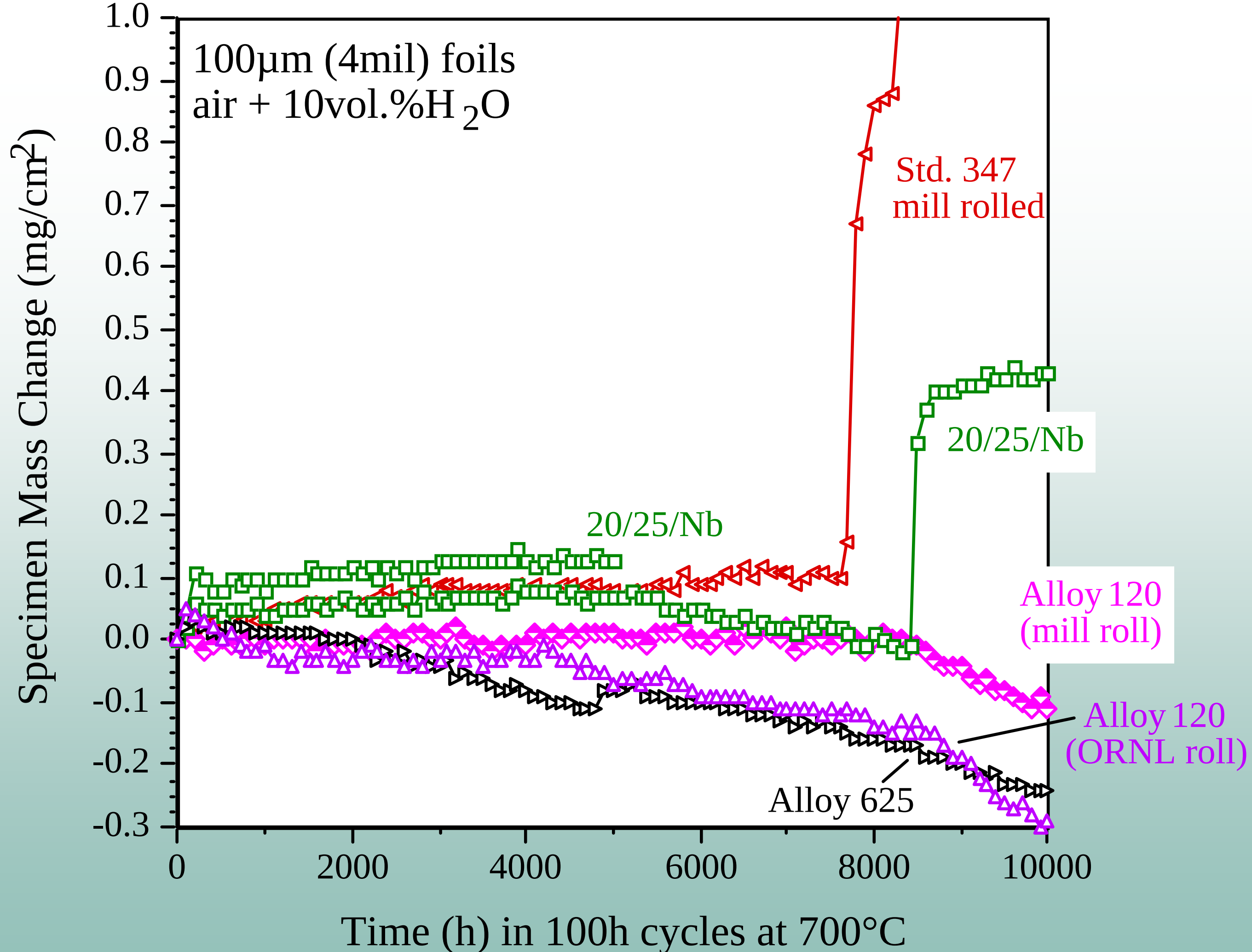

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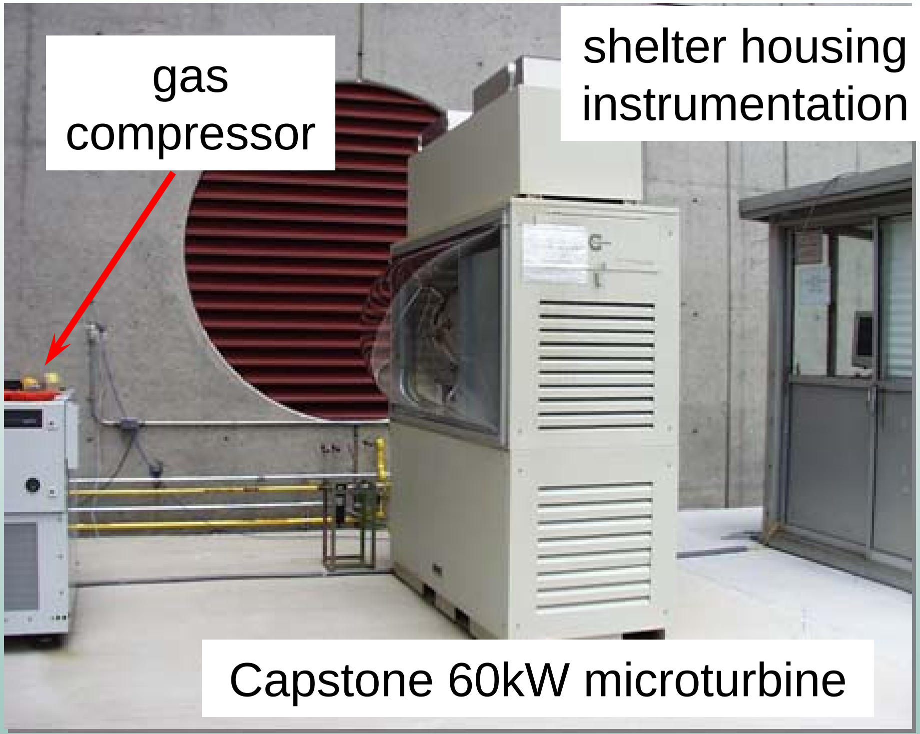
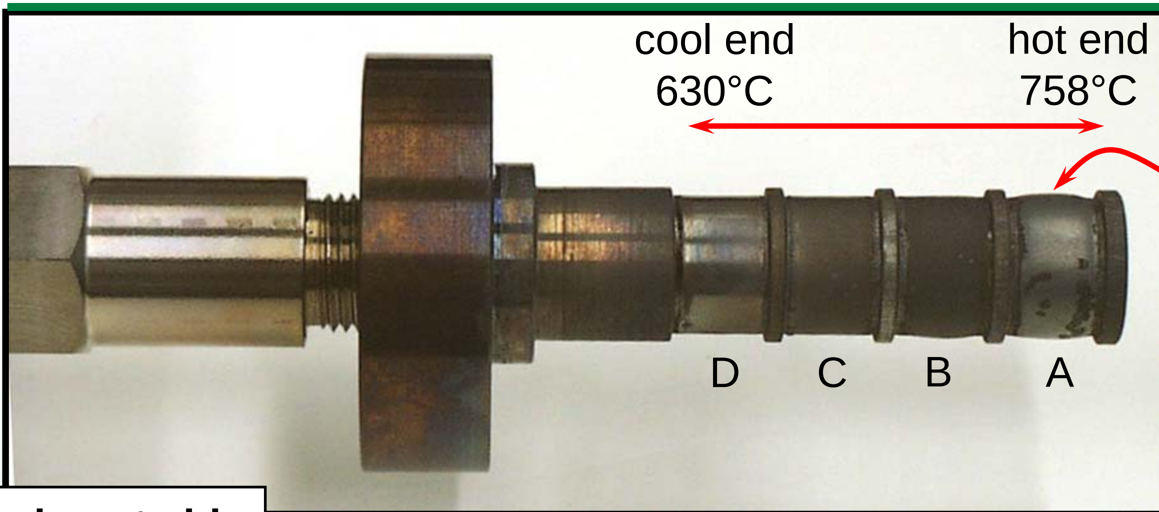
ORNL Microturbine Test Facility – Extends prior lab testing to the real turbine environment

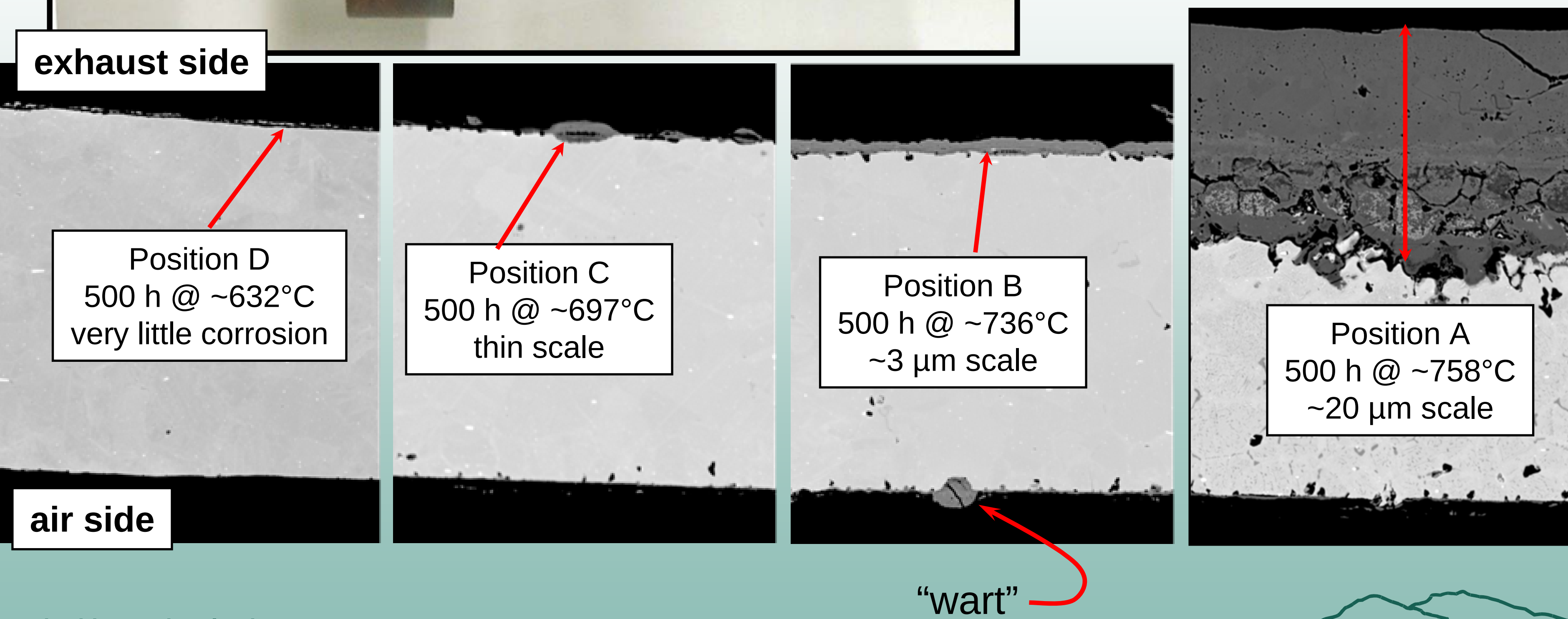
As part of the Advanced Materials for Recuperators Program, ORNL established a microturbine test facility to screen and evaluate candidate materials for advanced microturbine recuperators



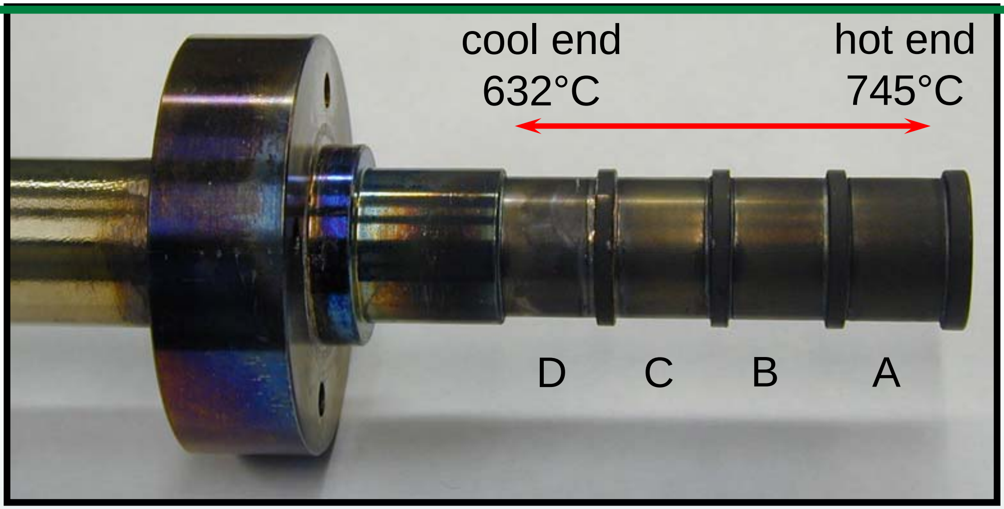
ORNL Microturbine data shows the same relative alloy rankings found for lab-scale testing: 347-stainless steel suffers after 500-hr exposure >700ºC



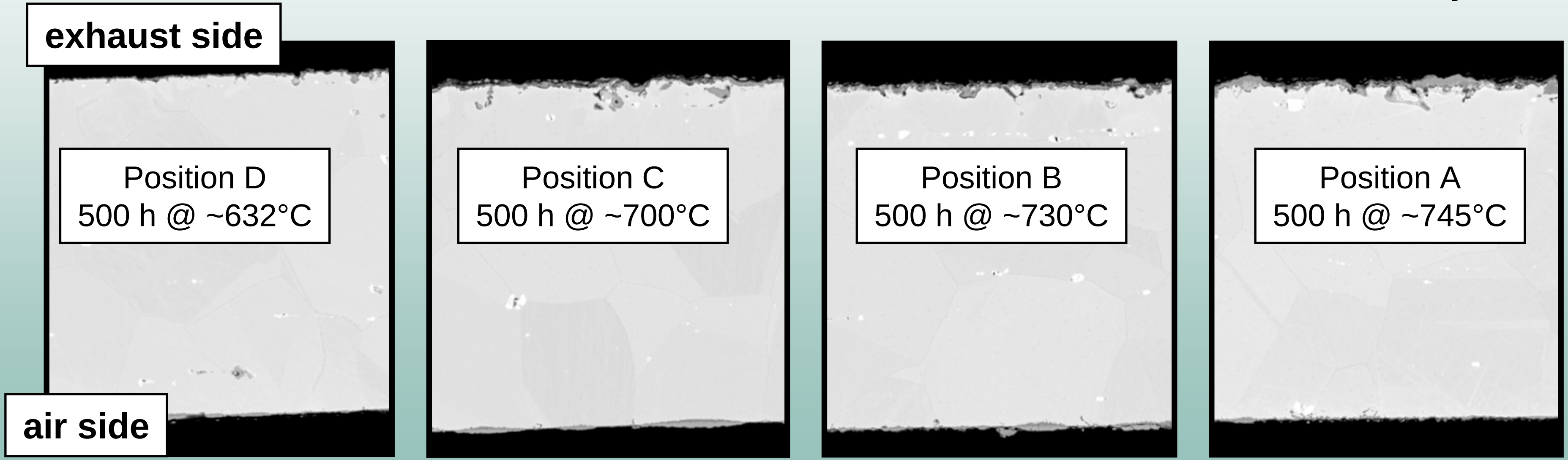
cross-sectional analysis



ORNL Microturbine data shows the same relative alloy rankings found for lab-scale testing: HR120 does well after 500-hr exposure up to 750C



cross-sectional analysis



Summary

- ORNL continues to build a high quality data base on creep and oxidation effects on various commercial alloys used or available for sheet/foil recuperators
- Alloy 625 is a good high-performance alternative to 347 steel at 700-750^{o}C and above
- HR120 and the new AL20-25+Nb are cost-effective, high-performance alternatives to 347 steel at 650-750^{o}C
- ORNL continues to work with recuperator end-users to address specific manufacturing issues, like welding and brazing, in addition to long term performance, and is correlating lab-tests with in-turbine testing