Compatibility Assessment of Advanced Stainless Steels In Sodium

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Steve Pawel
Oak Ridge National Laboratory

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Sodium Fast Reactors Derailed in the Early 1970s

- (re)gaining attention for sustainable expansion of nuclear energy

- require advanced materials with improved performance in high-temperature sodium compared to traditional materials (316L)

  - higher strength and creep resistance; similar compatibility

  - more options for design (higher temperatures and gradients)

  - promotes reliability and improved economics

examine performance of new alloys in sodium

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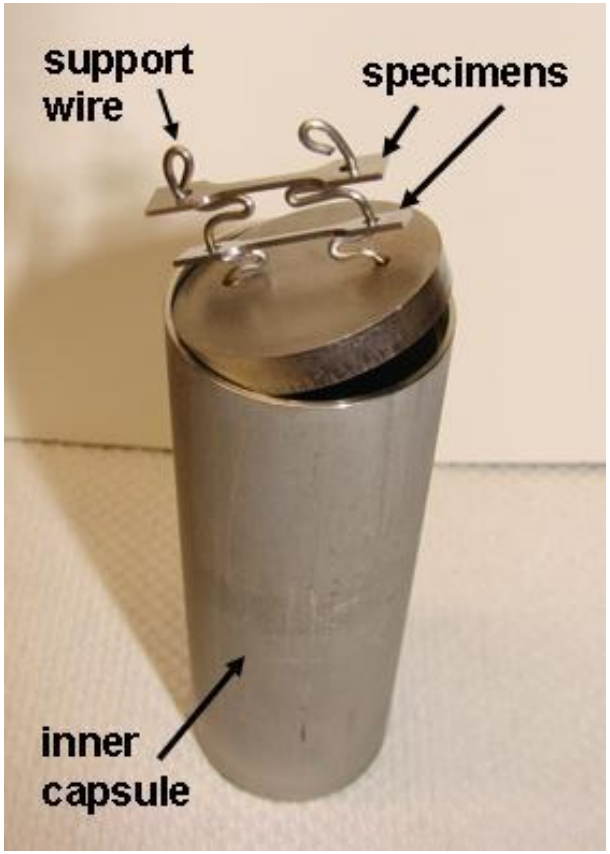
Capsule Exposures Used For Screening Tests



capsule hardware = 316L

test specimens
- 316L (austenitic, 17Cr-10Ni-2Mo)
- NF-616 (ferritic, 9Cr-0.5Mo-2W + Nb,V)
- HT-UPS (austenitic, 18Ni-13Cr-3Al + Nb)

test temperature = 600, 700°C

test duration = 100, 400 h

environment = commercially pure Na*
high-purity argon

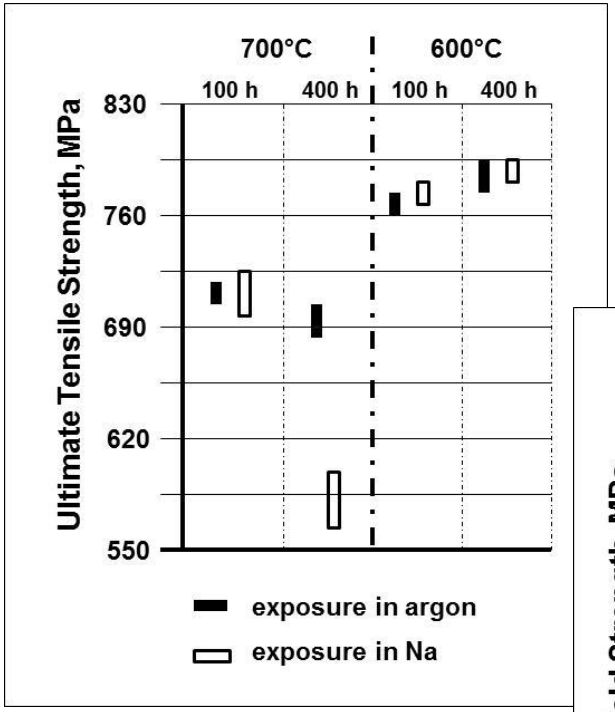
compare performance of 316L with new alloys;
evaluate potential for dissimilar metal effects
prior to operation of a thermal convection loop

Post-Exposure Capsule Handling and Results

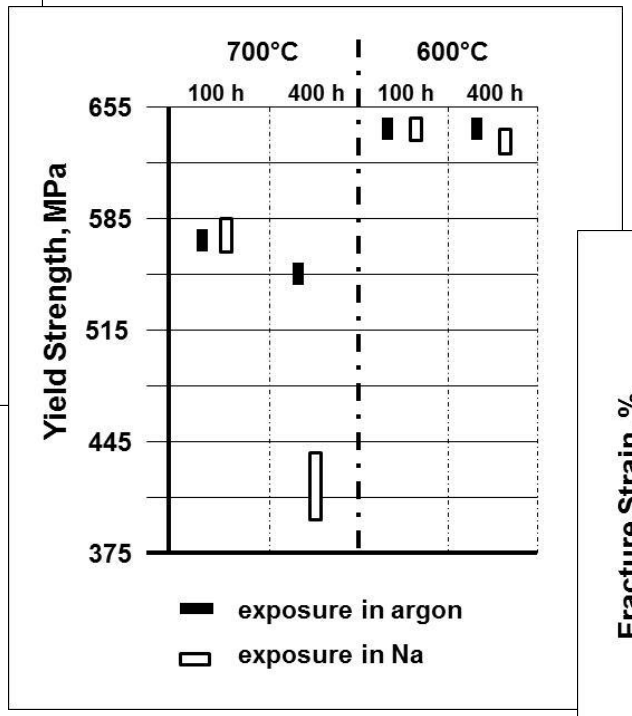
- Following exposure, capsules inverted to drain Na from specimens
- Capsules cut open in argon glove box, transferred to bench top for cleaning
- Specimens cleaned sequentially in ammonia, ethanol, and water to mitigate hydrogen charging of specimens

- for 316L and HT-UPS, only trace discoloration observed; original machining marks remain
- for 316L and HT-UPS, specimen weight and tensile properties unchanged within scatter indicated by argon exposures; no composition or structure gradients
- for NF-616, exposure at 700°C results in modest weight loss and substantial loss in strength

Tensile Properties of NF-616 Change as a Result of Exposure in Sodium at 700°C

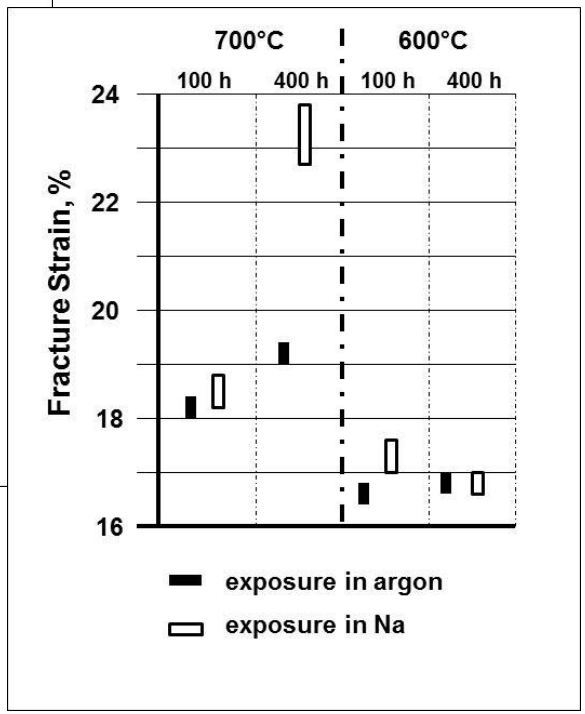


UTS



Yield

- UTS, YS decrease
- Ductility increases



Ductility

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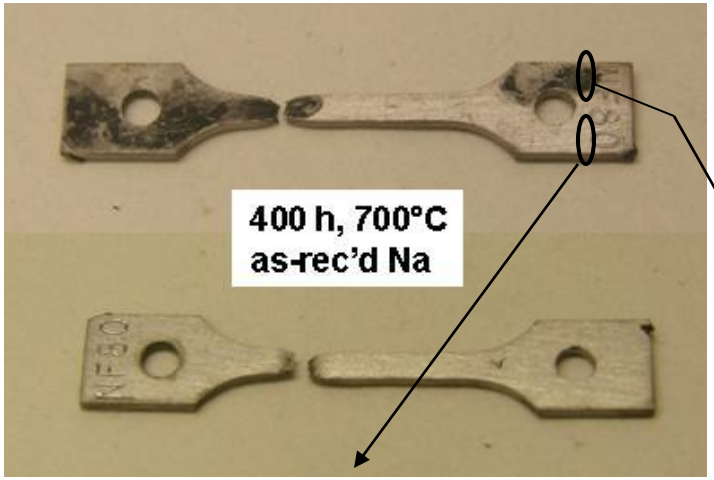
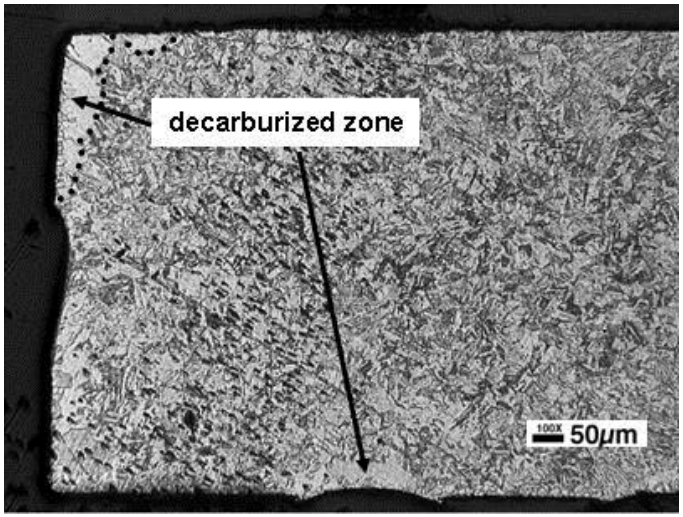
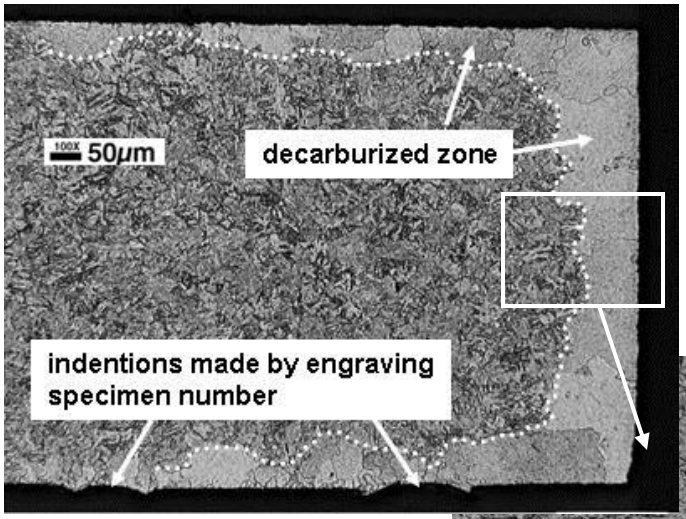
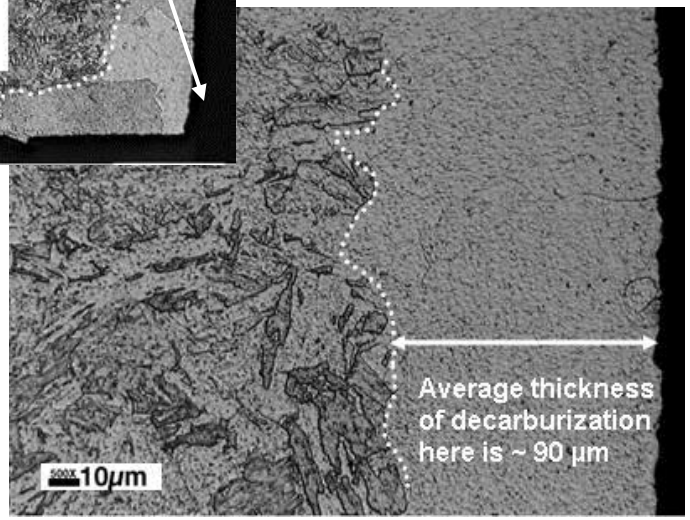
NF-616 Decarburized by Exposure to Na at 700°C









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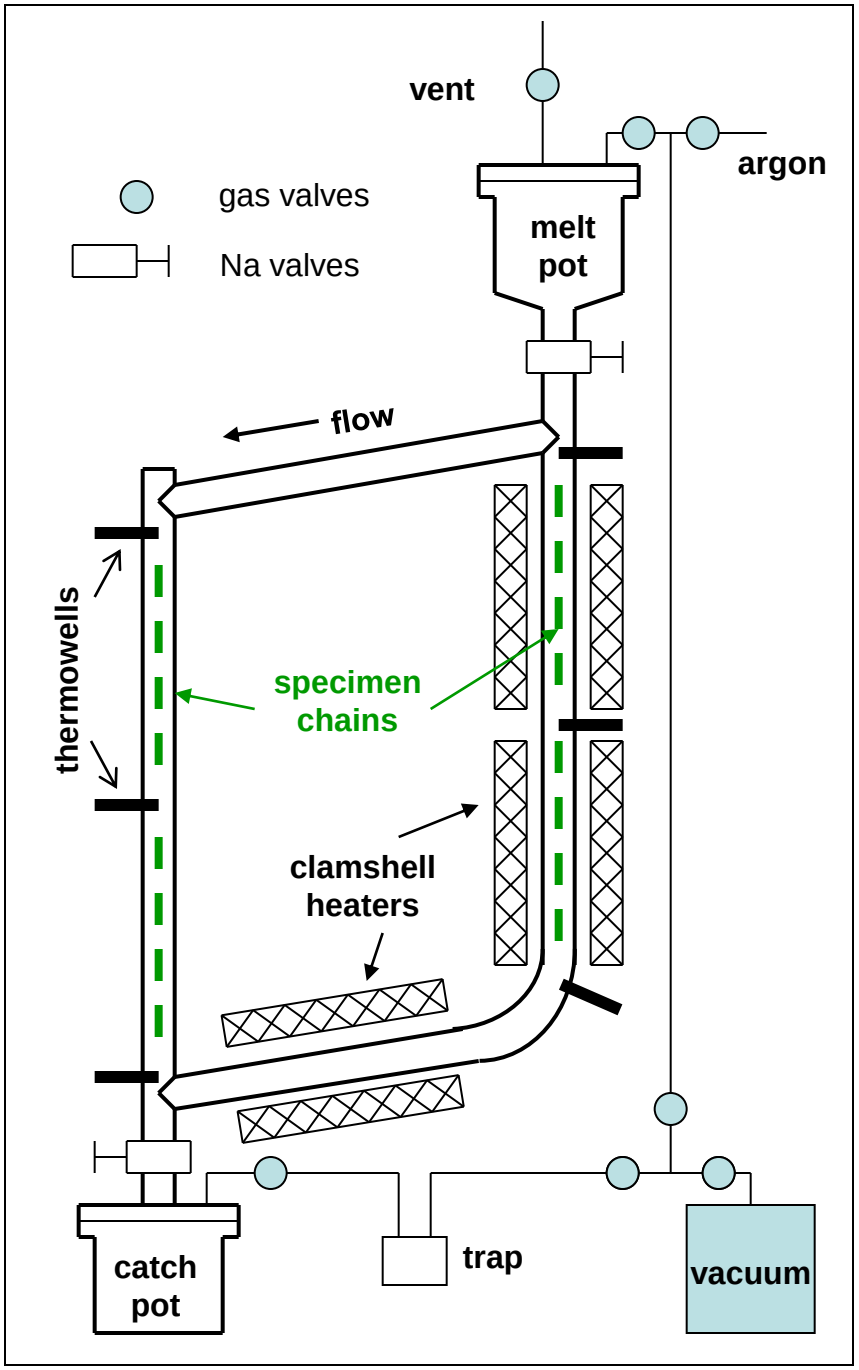
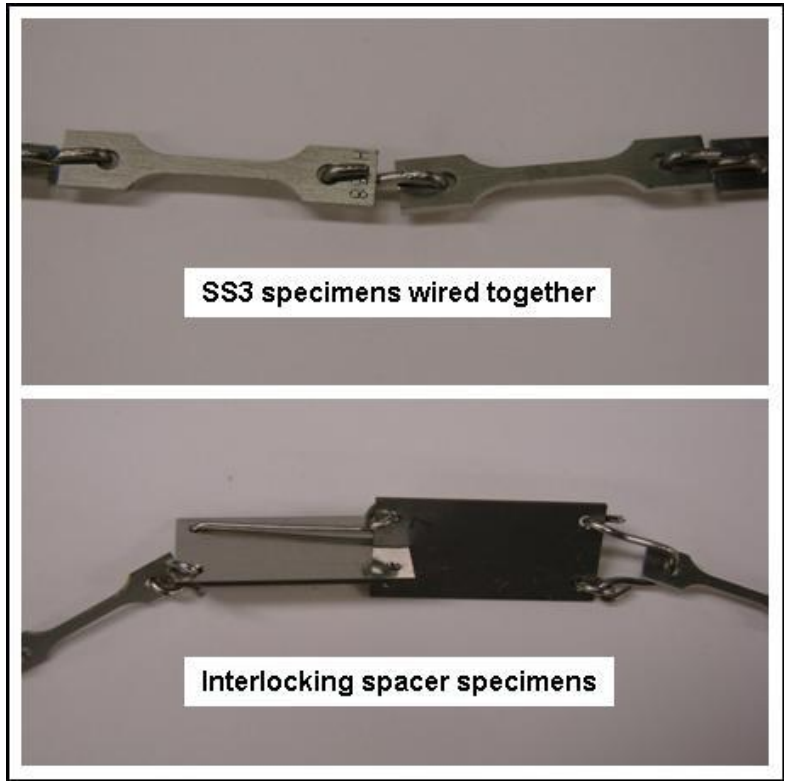
- attack not uniform across specimen surface
- decarb accounts for change in tensile properties
- weight loss corresponds to uniform corrosion rate of ~ 80 um/y, but decarb rate is much higher

Thermal Convection Loop and Specimens





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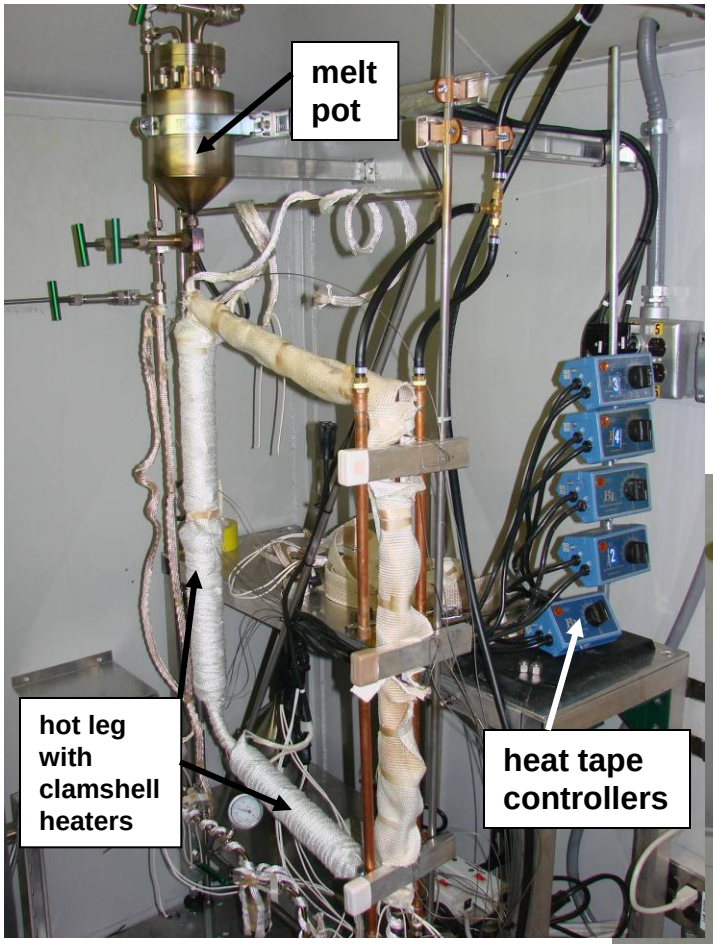
TCL under construction



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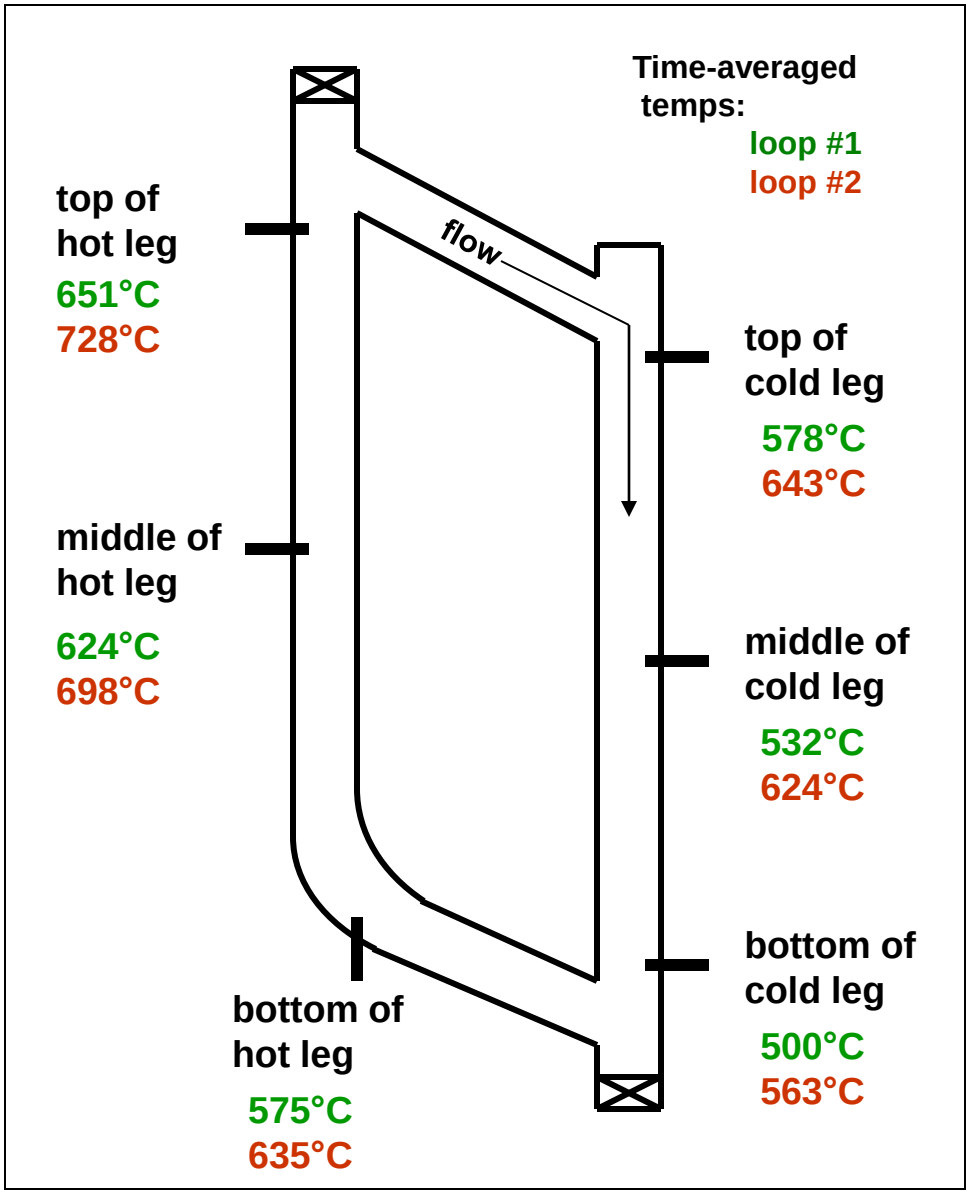

Two Thermal Convection Loops Operated for 2000 h

- commercially pure Na
- 316L and HT-UPS specimens (alternating position pattern)
- first loop with peak temp of 650°C and ΔT of 150°
- second loop operated identically but with all temps increased about 75° (to ~725°C)
- flow rates ~ 1 m/min

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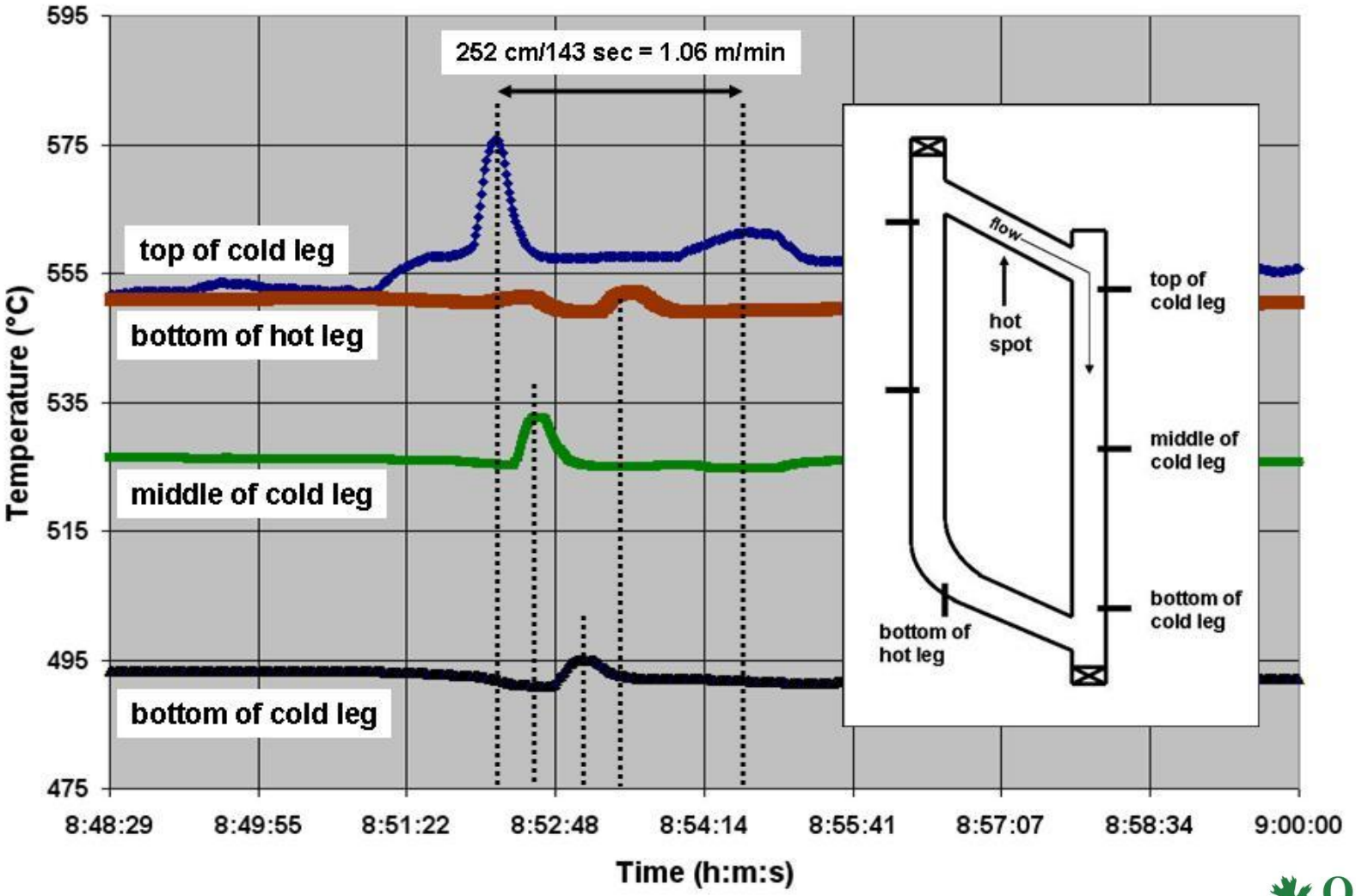
Snapshot of a “hot spot” test result



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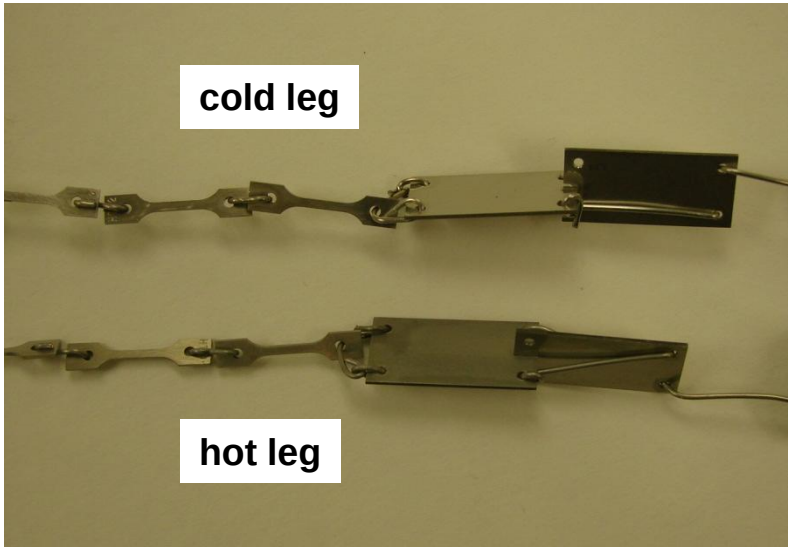
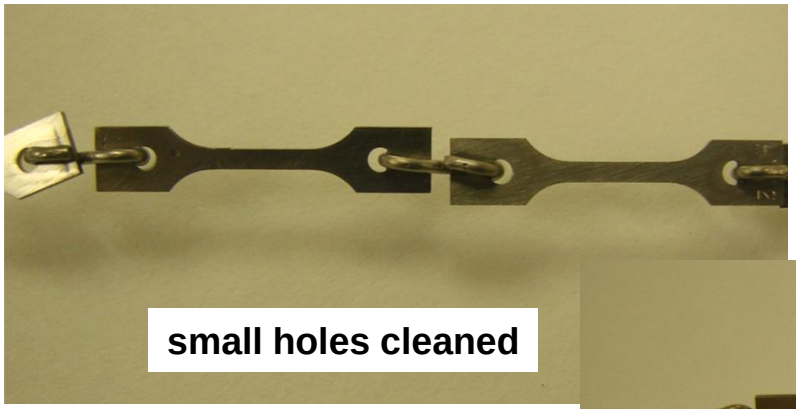
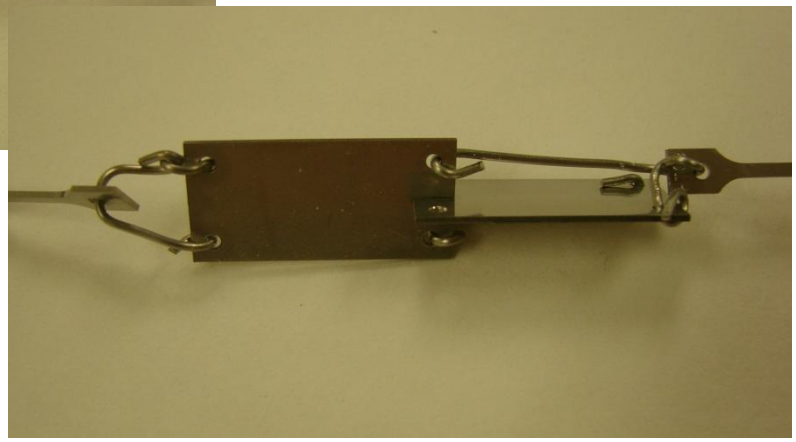
Results for TCL #1 (650˚C peak)







316L and HT-UPS specimens essentially unchanged

- effectively cleaned
- minor discoloration
- weight change insignificant
- no structure or composition changes (leaching, deposits)
- no Na-induced change in tensile properties

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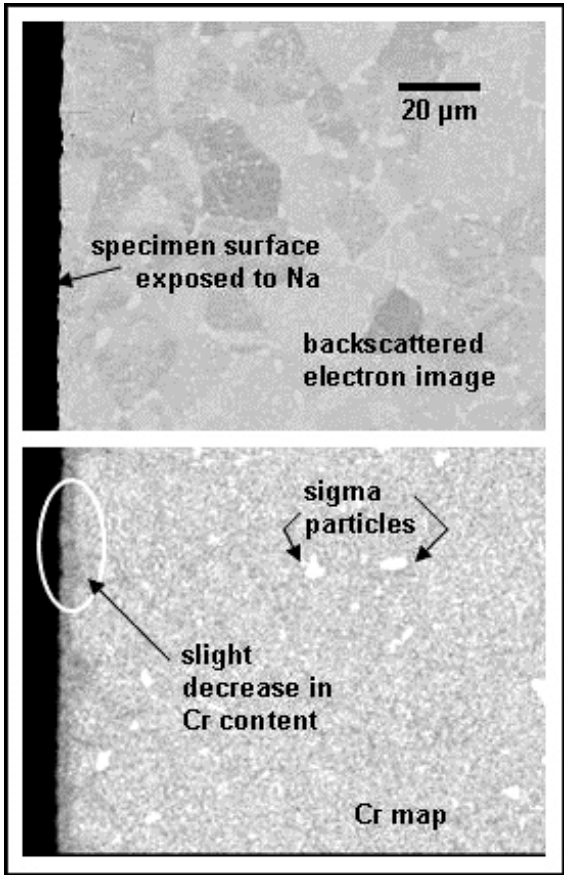
Results for TCL #2 (725˚C peak) almost identical to those from TCL #1 …

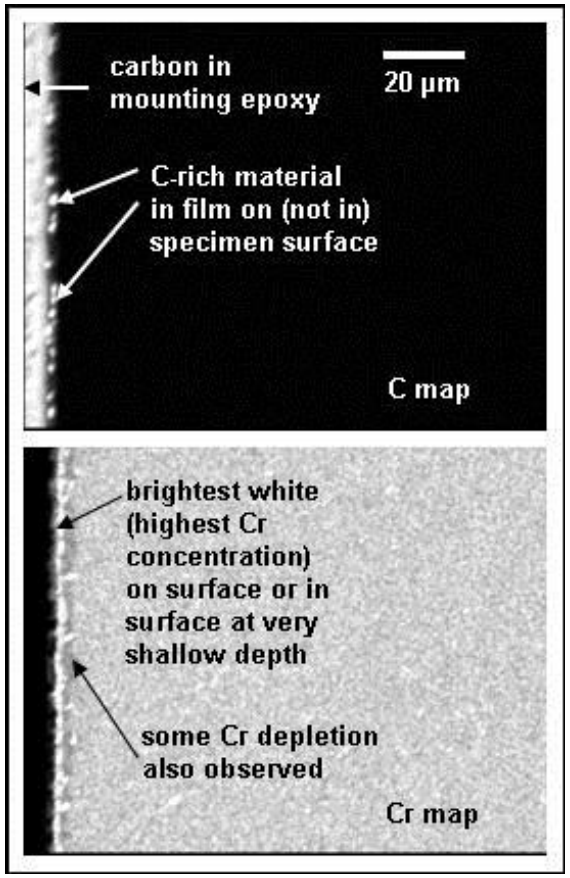


316L specimen from top of hot leg

Slight weight loss from topmost specimens in hot leg; -5% in UTS/YS and modest Cr depletion

Cold leg specimens experience larger weight gains than in Loop #1; deposit may incorporate C and Cr

HT-UPS exhibited even less response to sodium than 316L for these conditions



316L specimen from bottom of cold leg

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Conclusions

- **HT-UPS compares very favorably with 316L in terms of sodium compatibility**

  HT-UPS appears appropriate for extended development and testing (long-term exposures; properties in sodium with variable chemistry, etc.)

  For comparison, the yield strength after 400 h at 600˚C in argon was
  - **263 MPa for 316L**
  - **556 MPa for HT-UPS**

- **NF-616 was found to be susceptible to rapid decarburization in sodium**

  more alloy development required to render this alloy more compatible with sodium

On-Going Work (data analysis underway)

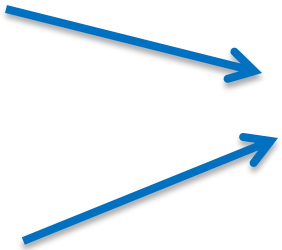
Duplicate previous capsule test effort, but concentrate on candidate alloys strengthened primarily with nitrogen additions

Ferritic alloys

- **(a) steel 1536**
  - **9Cr-0.5Mo-0.06N, two microstructure conditions**
- **(b) steel N1**
  - **9Cr-0.5Mo-2W-0.02N**
- **(c) steel C6-3**
  - **9Cr-2.5W-4Cu-0.25V-0.08N**

Austenitic alloys

- **(a) CF8C+**
  - **multiple heats; 19Cr-12Ni ... + Nb, up to 0.27N**
- **(b) NF-709**
  - **25Cr-20Ni-2Mo-0.2Nb-0.18N**
- **(c) HT-UPS**
  - **multiple heats; 14Cr-16Ni … + Nb, V, Ti, modest N additions**
- **(d) 316L**
  - **for comparison**



Best performers graduate to TCL exposures

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Acknowledgments

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  - managed at ORNL by J. Busby

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