Advanced Pressure Boundary Materials: Evaluation of Specification Ranges for Creep-Strength-Enhanced Ferritic Steels

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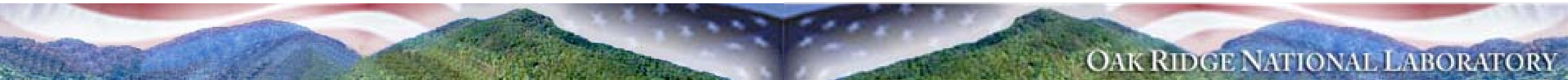


Purpose is to build fundamental understanding of materials behavior needed to increase operating temperatures

Activities bridge basic & applied R&D on ferritic steels, austenitic steels and Ni-based alloys

- CRADA with Alstom Power, Inc. - "*Analysis of Off-Normal Metallurgical Conditions on the Performance of Advanced Cr-Mo Steels*"
- MOA with Central Research Institute of Electric Power Industry (CRIEPI), Japan - "*Joint Research on Properties of Alloy 263 and 263 Weldments*"
- Collaboration with National Institute for Materials Science (NIMS), Japan - "*Mechanisms of Type IV Weld Failures in Cr-Mo Steels*"
- Involvement with materials issues relating to the ASME Boiler and Pressure Vessel Code (Section II: Materials)
- Technical support for DOE/OCDO Ultrasupercritical Steam Boiler Consortium not included in defined ORNL Tasks

PWHT is almost always required for 9-12Cr steel components built to ASME B&PV Code

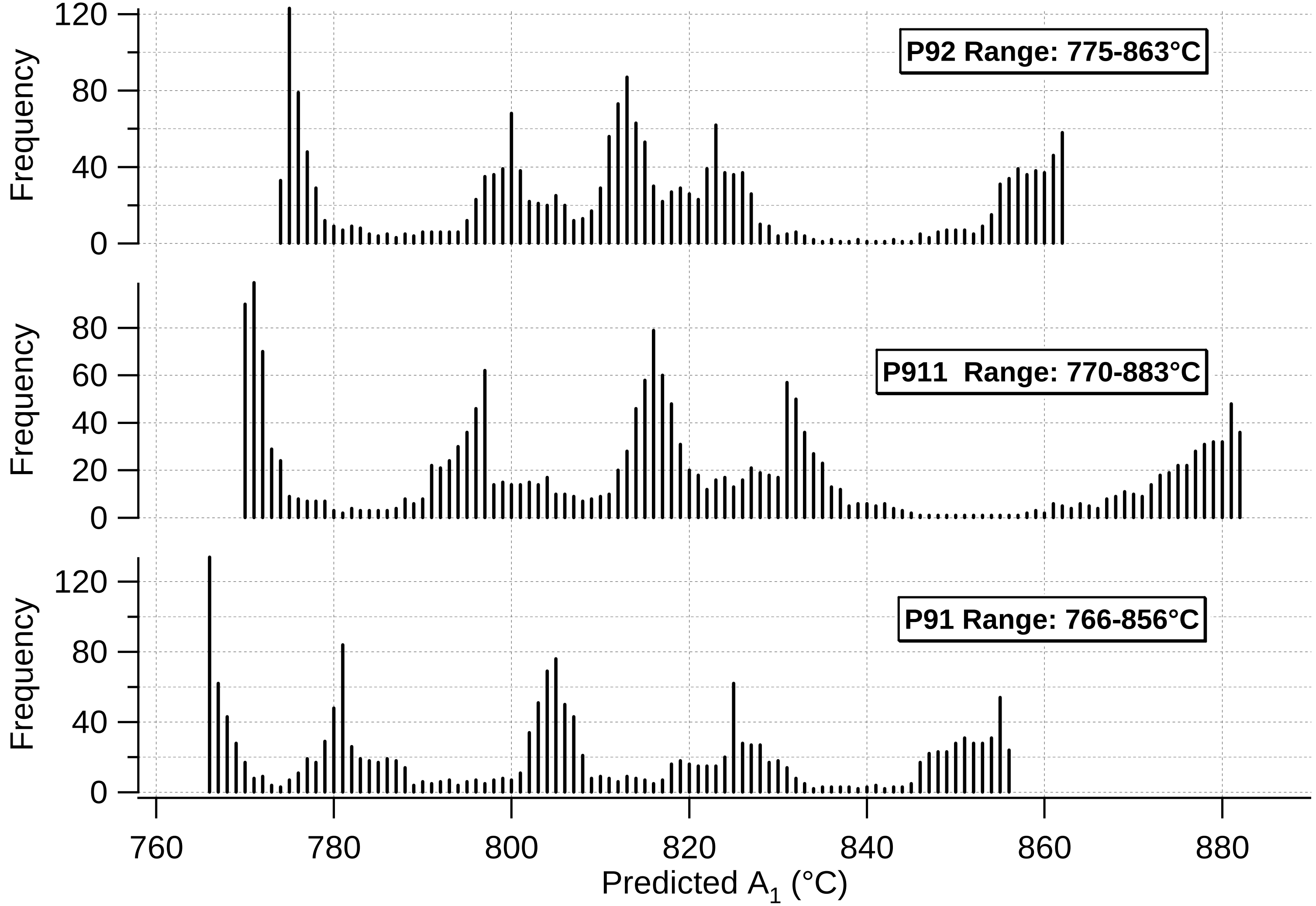
- ASME Code specifies minimum of 704°C
- No maximum PWHT temperature is specified
  - Expectation is that critical temperatures will not be exceeded (*want tempered, not untempered*)
- No comprehensive information about temperature limits is available
  - Fabricators often PWHT at temperatures well above 704°C to minimize processing time and reduce cost

How high is too high for PWHT of 9-12 Cr steels?

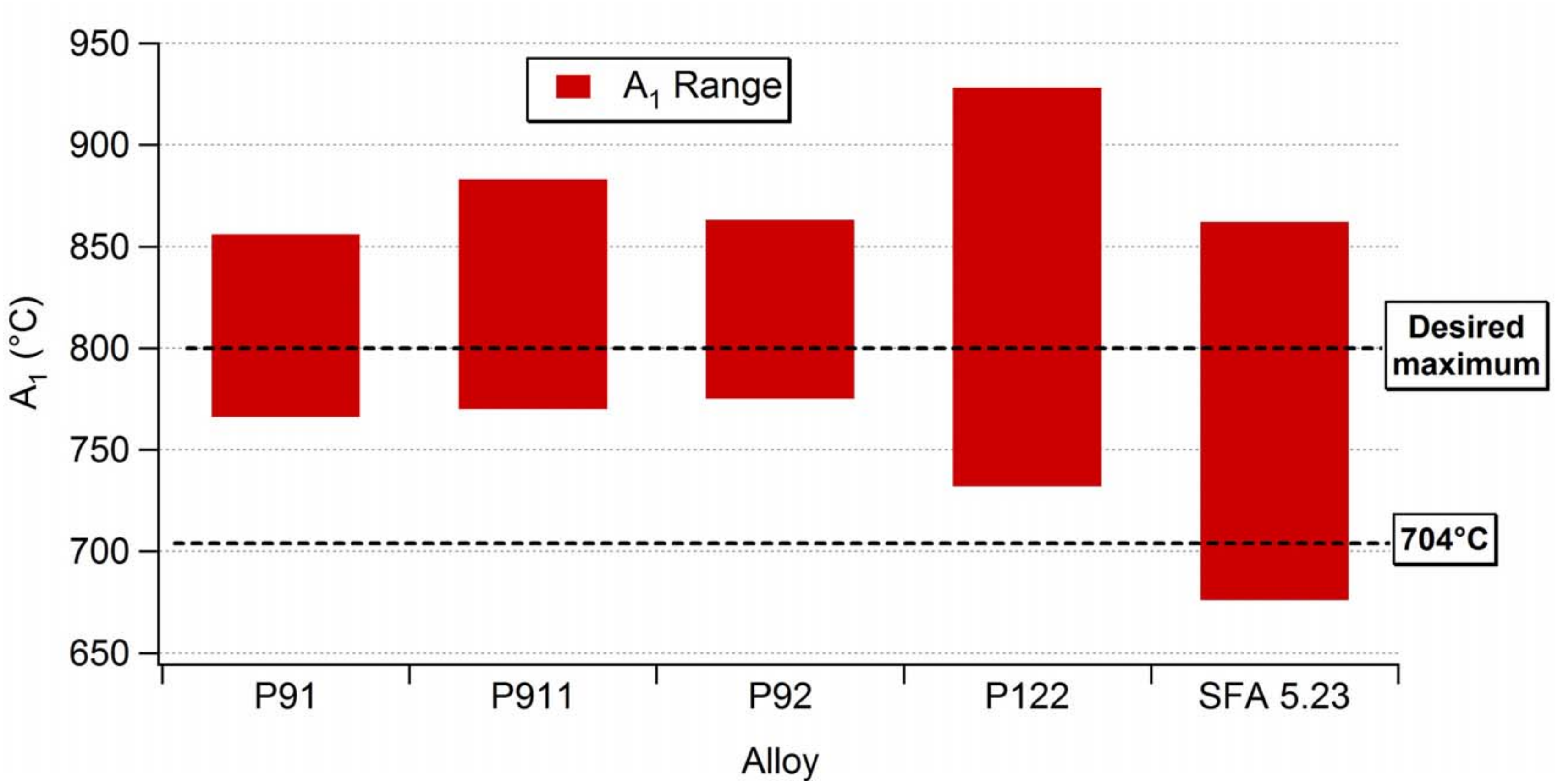
Critical temperatures for PWHT are being reevaluated for ASME B&PV Code

- **P91 – A387 Gr 91:**
  - Fe-0.1C-0.4Mn-0.3Si-9Cr-1Mo-0.1Ni-0.2V-0.08Nb-0.05N, wt%
- **P911 – A387 Gr 911:**
  - Fe-0.1C-0.4Mn-0.3Si-9Cr-1Mo-0.1Ni-0.2V-0.08Nb-0.06N-1W, wt%
- **P92 – 9Cr-2W Material:**
  - Fe-0.1C-0.4Mn-0.3Si-9Cr-0.3Mo-0.1Ni-0.2V-0.07Nb-0.05N-1.8W, wt%
- **P122 – 12Cr-2W Material:**
  - Fe-0.1C-0.4Mn-0.3Si-11Cr-0.4Mo-0.2Ni-0.2V-0.07Nb-0.07N-2W-1Cu, wt%
- **Weld metal:**
  - SFA 5.23 B9 – 9Cr submerged arc weld deposit

A_1 ranges can be estimated using computational thermodynamics



Thermodynamic analysis provided a systematic, scientific basis for defining PWHT limits



- ASME B&PV Code committees are preparing to revise PWHT & stress relief rules based on our analysis

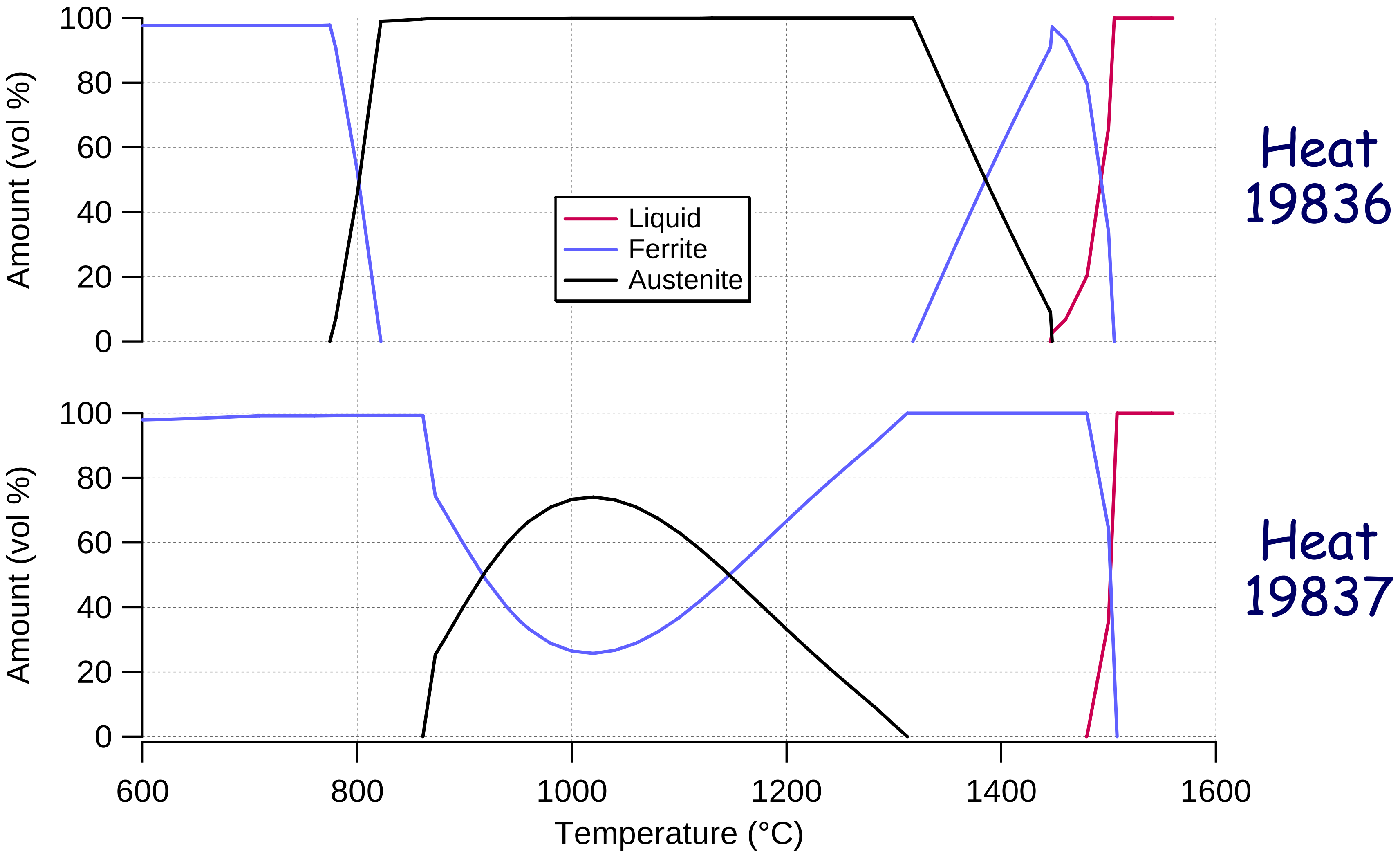
Other implications of ASTM specified composition ranges are being investigated

	Grade 91 Composition, wt%								
ID	C	Mn	Si	Cr	Mo	Ni	V	Nb	N
Min.	0.06	0.25	0.18	7.90	0.80	0.00	0.16	0.05	0.025
Max.	0.15	0.66	0.56	9.60	1.10	0.43	0.27	0.11	0.08
19836	0.11	0.62	0.16	8.12	0.81	0.44	0.167	0.05	0.024
19837	0.041	0.25	0.53	9.63	1.12	0.01	0.283	0.11	0.014

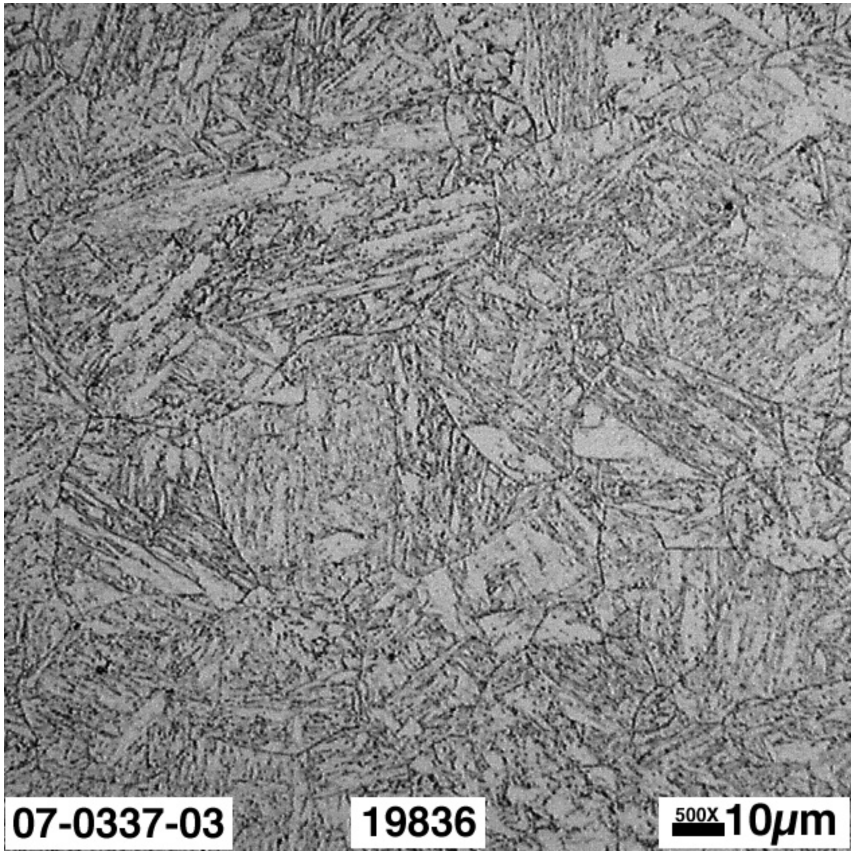
- Ht 19836: high γ-formers + low α-formers
- Ht 19837: low γ-formers + high α-formers

How do extremes of composition range affect properties?

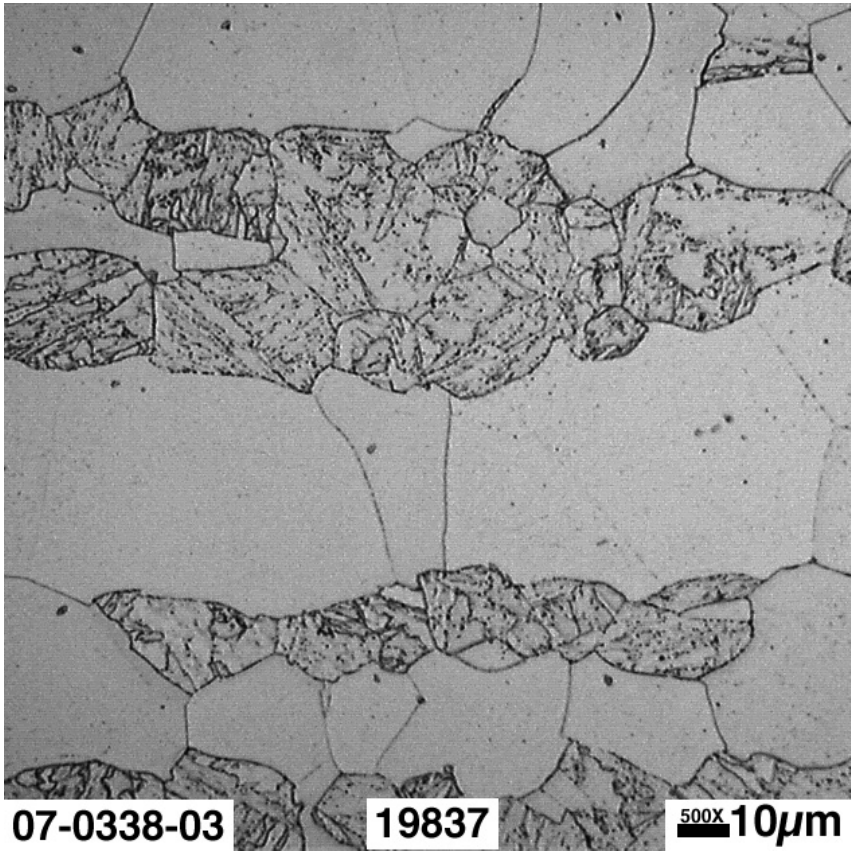
Compositions near P91 chemistry limits produce wide microstructure variations



Metallographic examination confirmed predicted microstructure variation

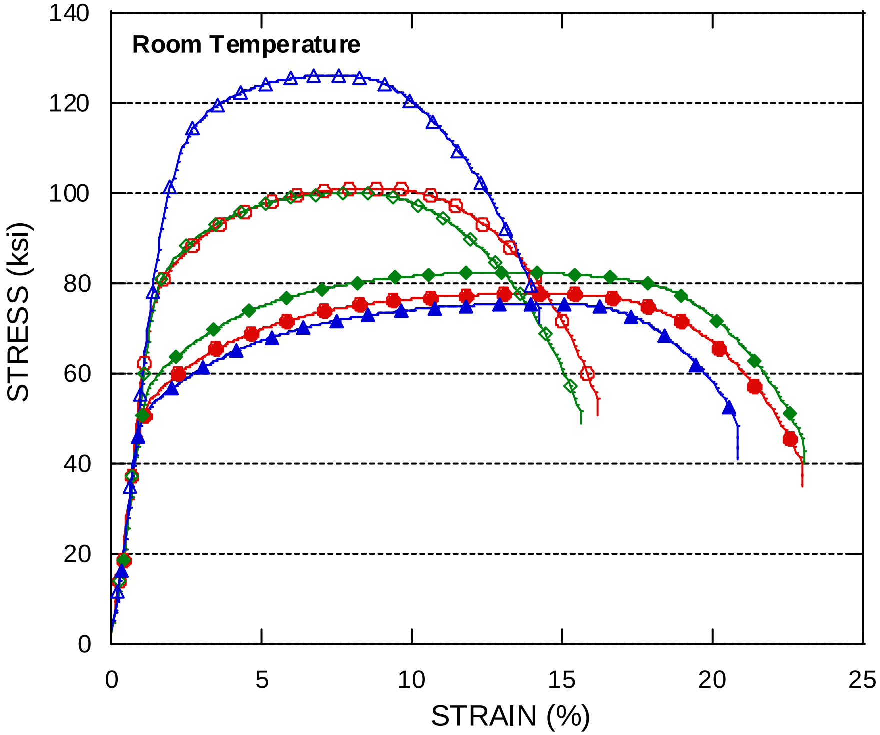


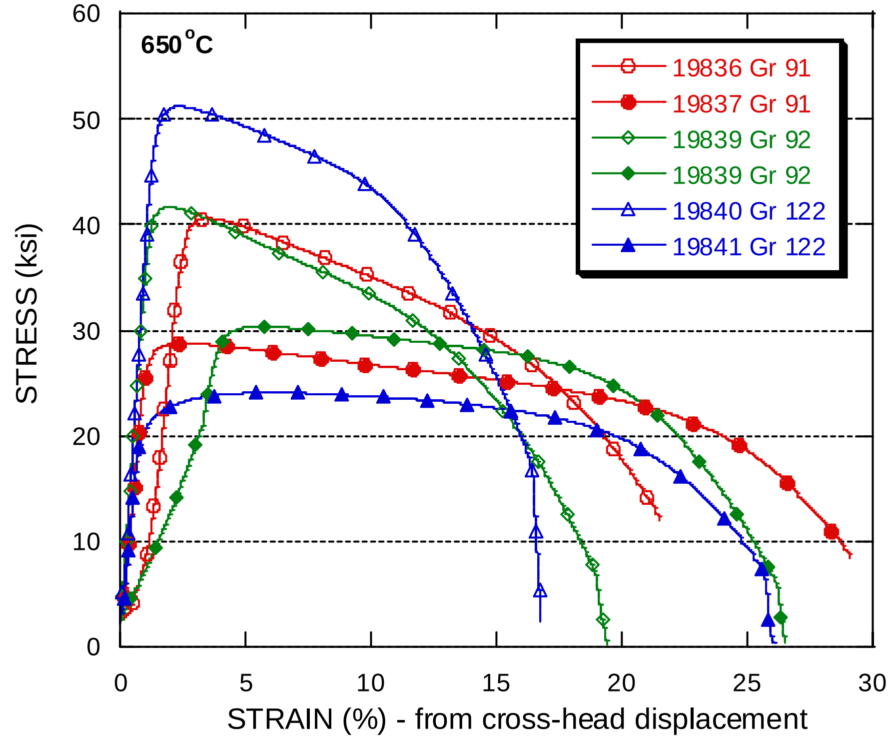
100% martensite



Martensite + ferrite

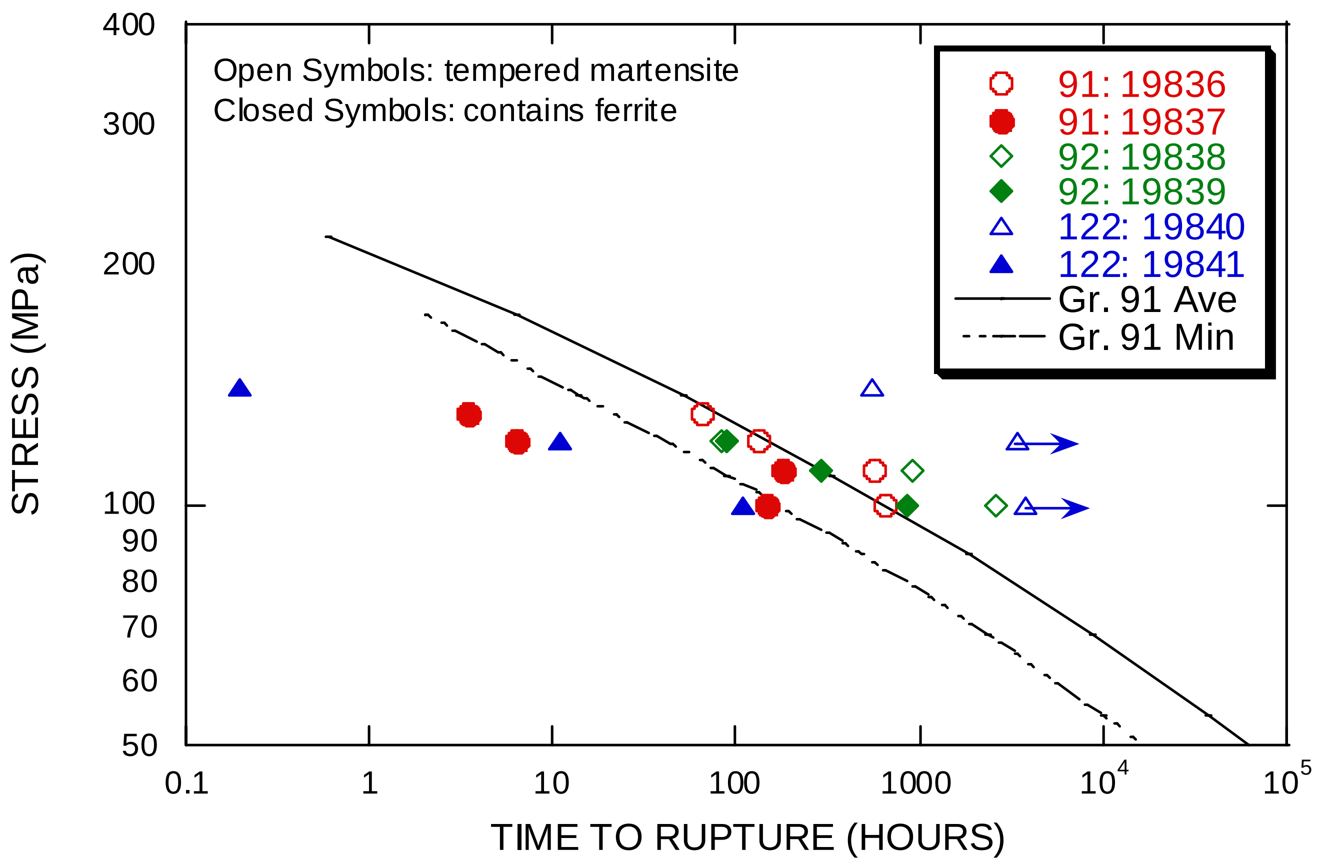
Results of tensile testing – ferrite reduces strengths





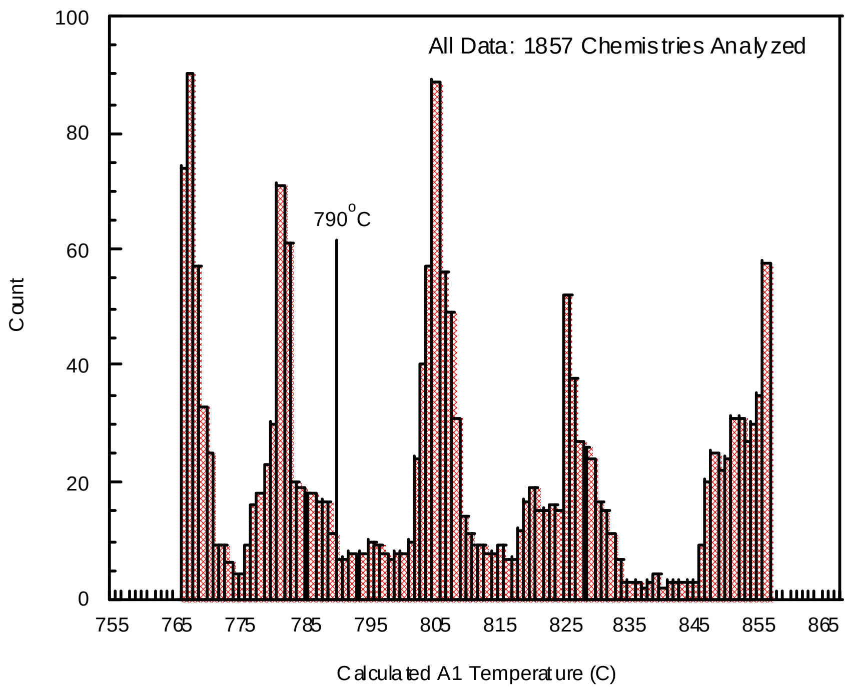
- Tensile behavior is identical at R.T. with ferrite present
- Trend is similar for 650°C tests

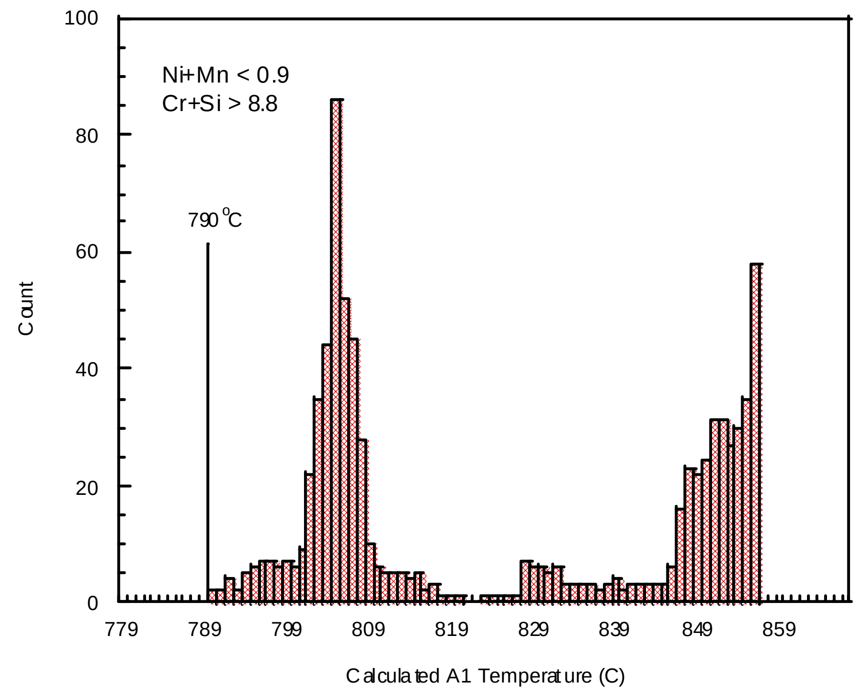
Ferrite reduces creep strength



- Alloy compositions should be controlled to avoid ferrite

Composition analysis will be used to restrict specified ranges





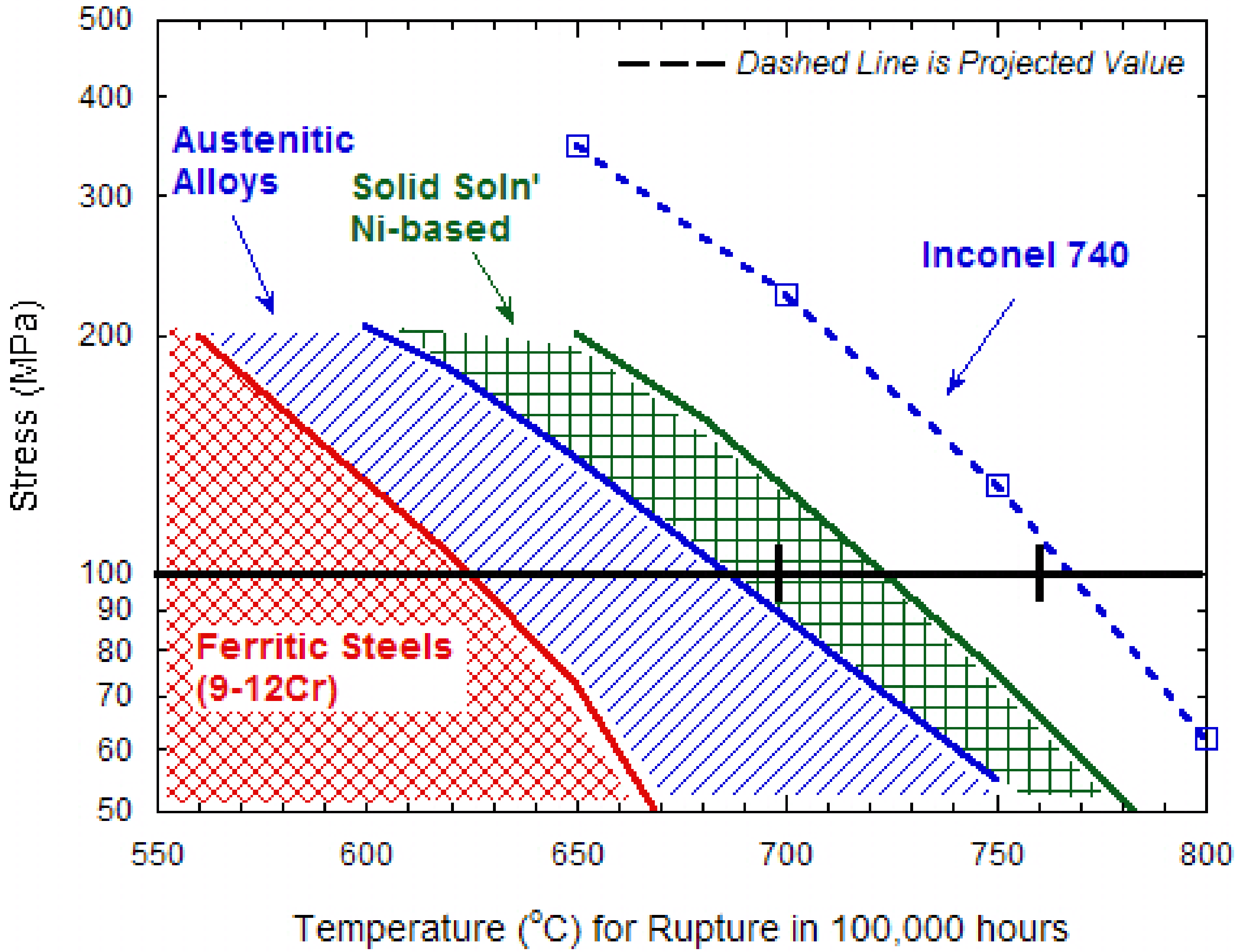
- Composition range restricted by lower critical temperature will ensure tempering does not exceed A_1
- Further analysis to restrict composition range to avoid δ-ferrite formation is in progress

Conclusions: *Evaluation of Specification Ranges for Creep-Strength-Enhanced Ferritic Steels*

- Composition ranges for 9-12 Cr-Mo steels were reevaluated using computational thermodynamics
  - Science-based, systematic, economical
  - Accuracy of predictions is high
- δ-ferrite has a significant negative affect on both tensile and creep properties of 9-12 Cr-Mo steels
- Composition of A387 Grade 91 can be restricted to:
  - Permit PWHT up to 790-800°C
  - Insure that retained δ-ferrite is avoided (in progress)

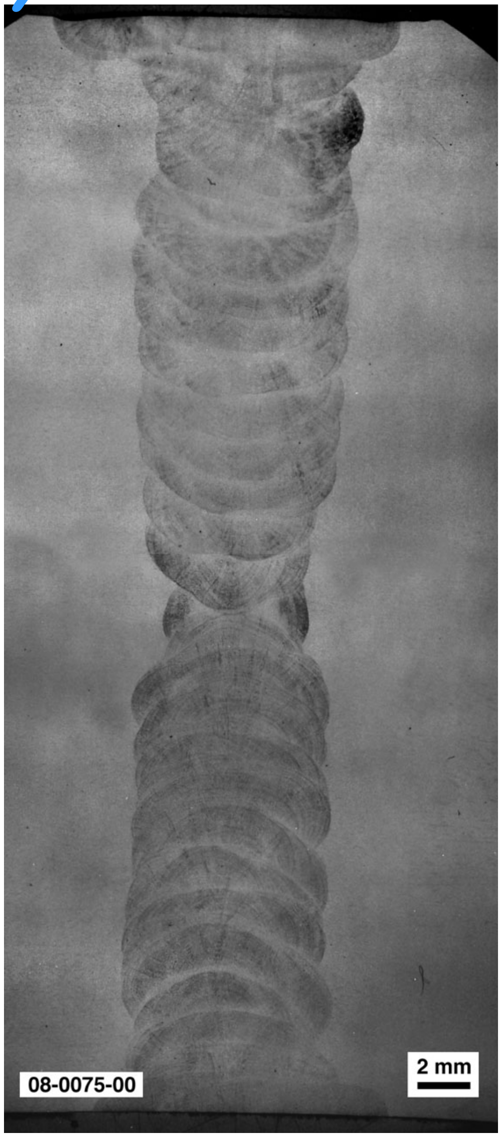
Research supported by the U.S. Department of Energy (DOE), Office of Fossil Energy, Advanced Research Materials Program

Age-hardenable Ni-based alloys are required to meet DOE objectives for Fossil Energy Systems like USC Steam Boilers



Weldment strength and cyclic behavior are emphasized in R&D on Ni-based alloys

- Thermodynamic assessment of the 263 system and potential weld metals was completed
  - Commercial thick-plate material for creep and weldment studies was procured
  - Gleeble simulations were done to produce simulated heat-affected-zone (HAZ) materials
  - Long-term creep-rupture tests were initiated on the plate to establish baseline behavior
  - NG-GTAW of thick plate was completed
- MOA-UTB 2006221 was executed with CRIEPI (Japan) to study the creep-fatigue properties of alloy weldments
- Visiting scientist from CRIEPI is performing creep-fatigue experiments at ORNL (no cost to ORNL) for 1 year



Advanced Pressure Boundary Materials

Highlights:

- Using unique capabilities and fundamental understanding to assist ASME and manufacturers in better informed use of advanced alloys
  - Using computational thermodynamic analysis to enable more robust alloy specifications
  - Supporting component design with testing and analysis of mechanical behavior
- Using advanced tools – like APS – to better understand new high-performance alloys
  - Collaboration with NIMS
- Leveraging resources to investigate ways to increase performance of Ni-based alloys
  - Collaboration with CRIEPI