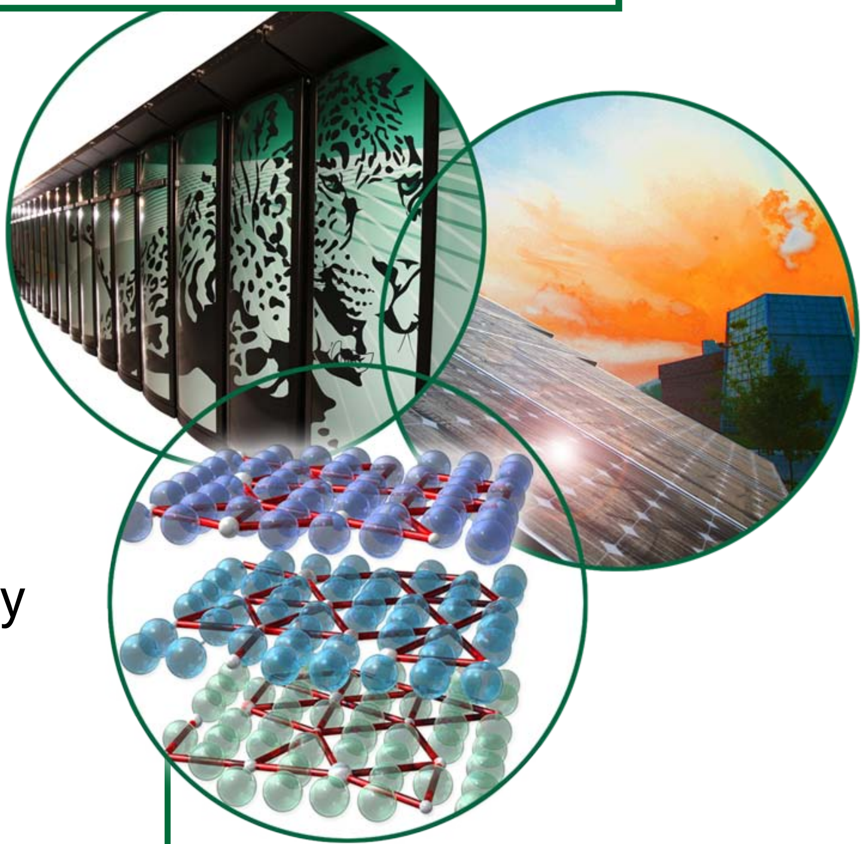
Improving the Performance of Creep-Strength-Enhanced Ferritic Steels



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Pittsburgh, PA

U.S. DEPARTMENT OF ENERGY

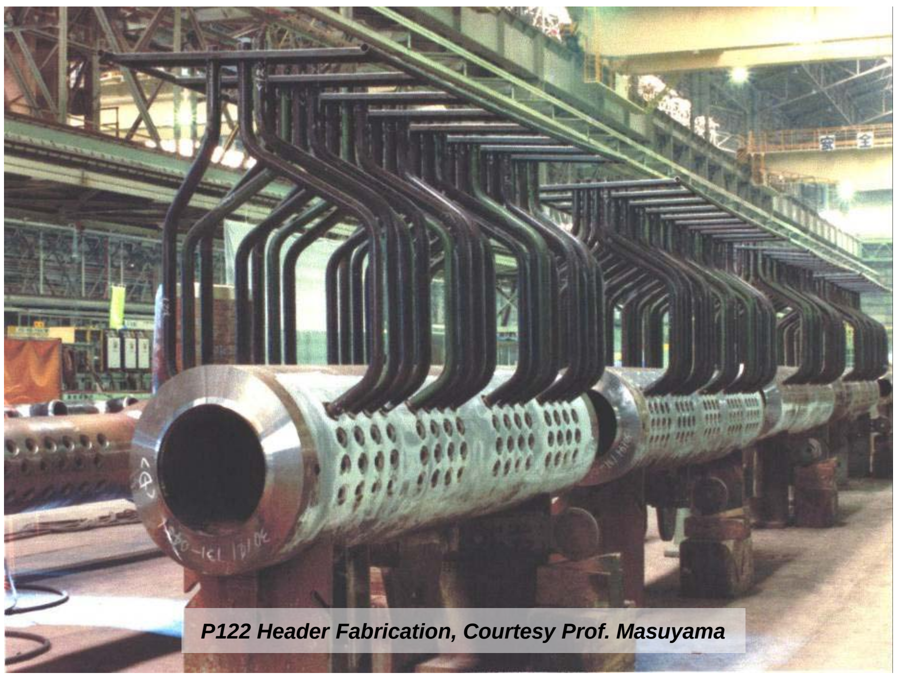
OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Purpose is to build fundamental understanding needed to maximize performance of CSEF steels

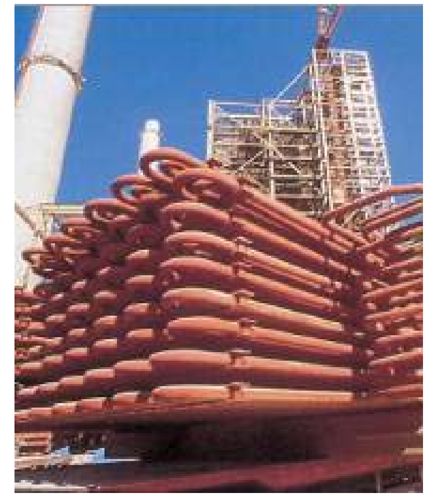
- Activities combine basic & applied R&D with strong power industry interactions
- Specific goals include:
  - Improving the structural performance of creep-strength-enhanced ferritic steels (9-12Cr-Mo steels)
  - Provide science-based guidelines for maximizing safe operating temperatures
  - Understand the fundamental causes of current temperature limitations
    - Causes of Type IV failures
    - Possible ways of minimizing/eliminating Type IV failures
  - Develop approaches for increasing practical operating temperatures

Estimated CSEF needs for construction of a High-Efficiency Boiler

- Headers & piping
  - P91/P92 – 1,000,000 lbs
- Boiler tubing
  - T23, T91, T92 Alloy Grades – 2,600,000 lbs

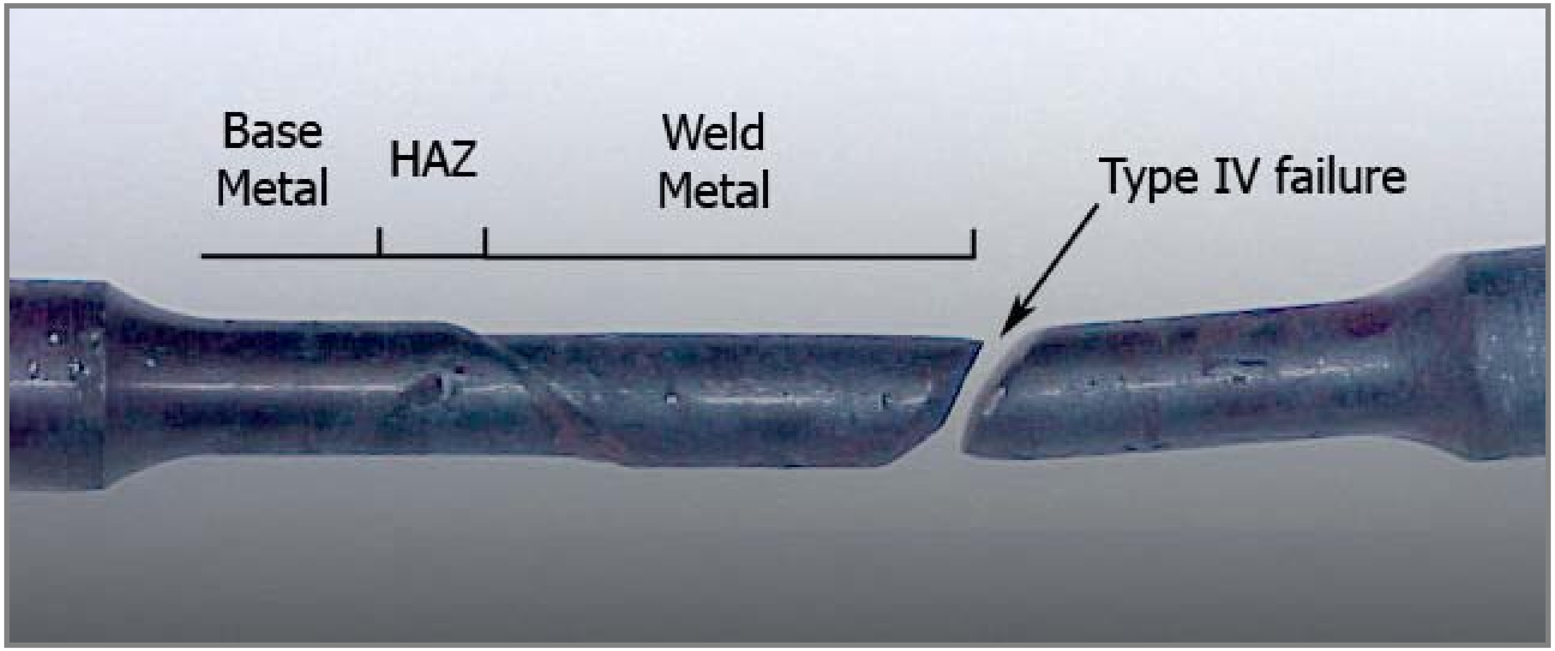


P122 Header Fabrication, Courtesy Prof. Masuyama



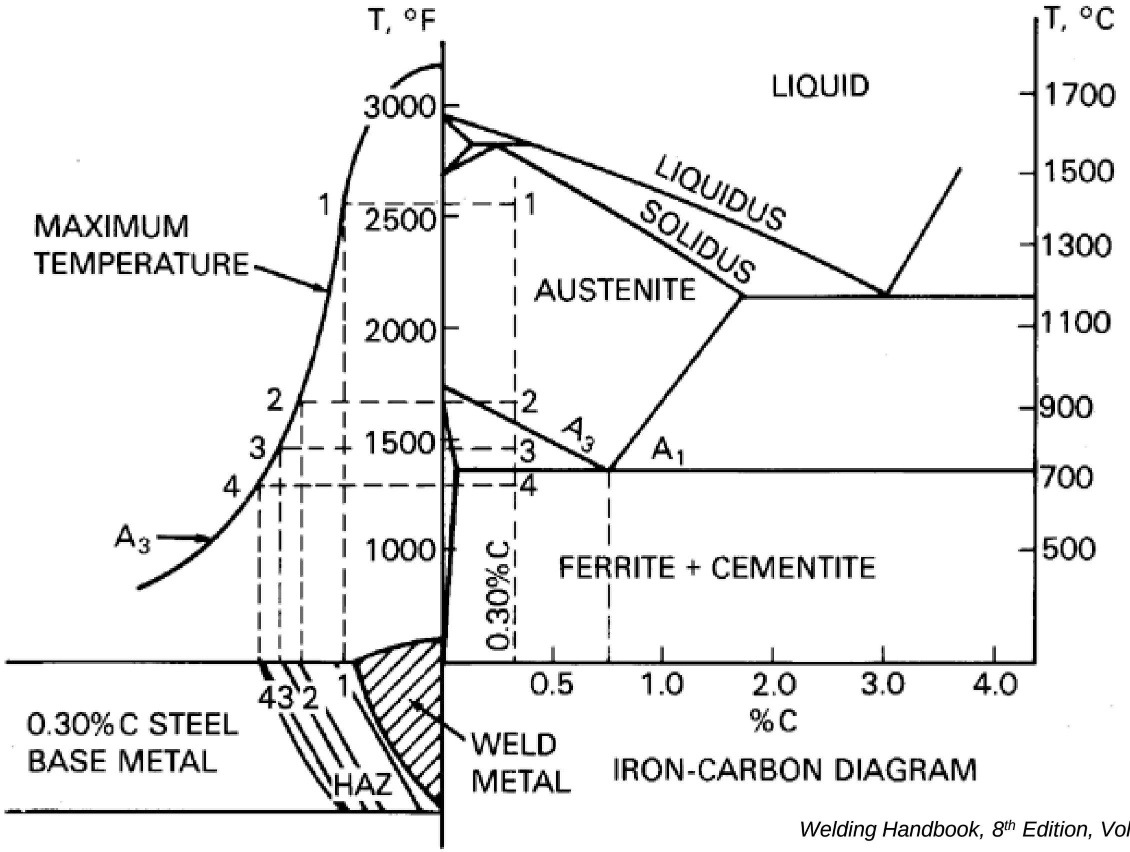
Images courtesy of The Babcock & Wilcox Company, www.babcock.com

Long-time weldment properties may not meet projections from short-time data



- Type IV failure of Cr-Mo steel welds is due to weakened microstructures in HAZs
- Unexpected behavior that causes unscheduled, premature utility outages

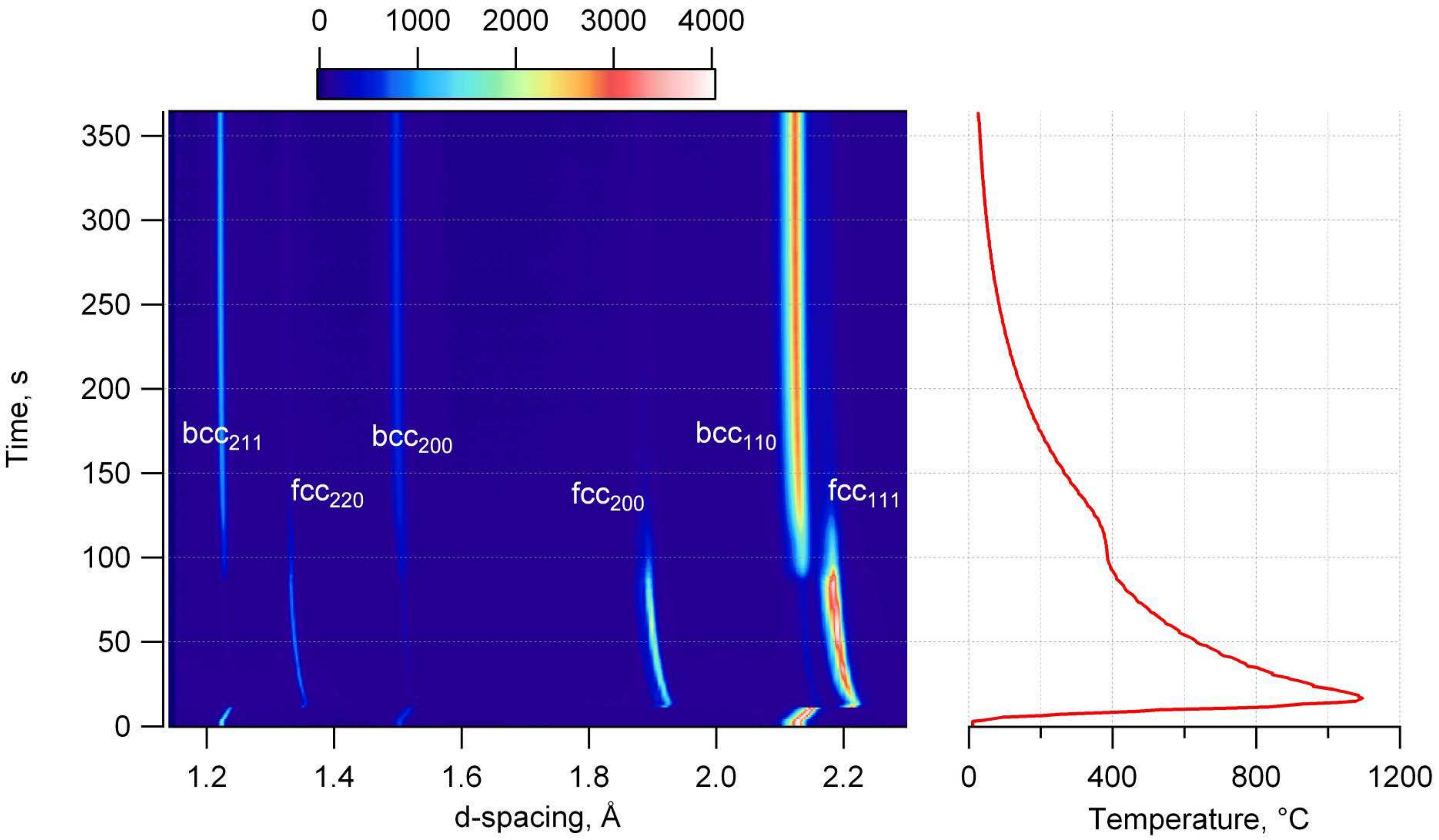
Type IV failures depend on gradients of microstructures/properties in weld HAZs



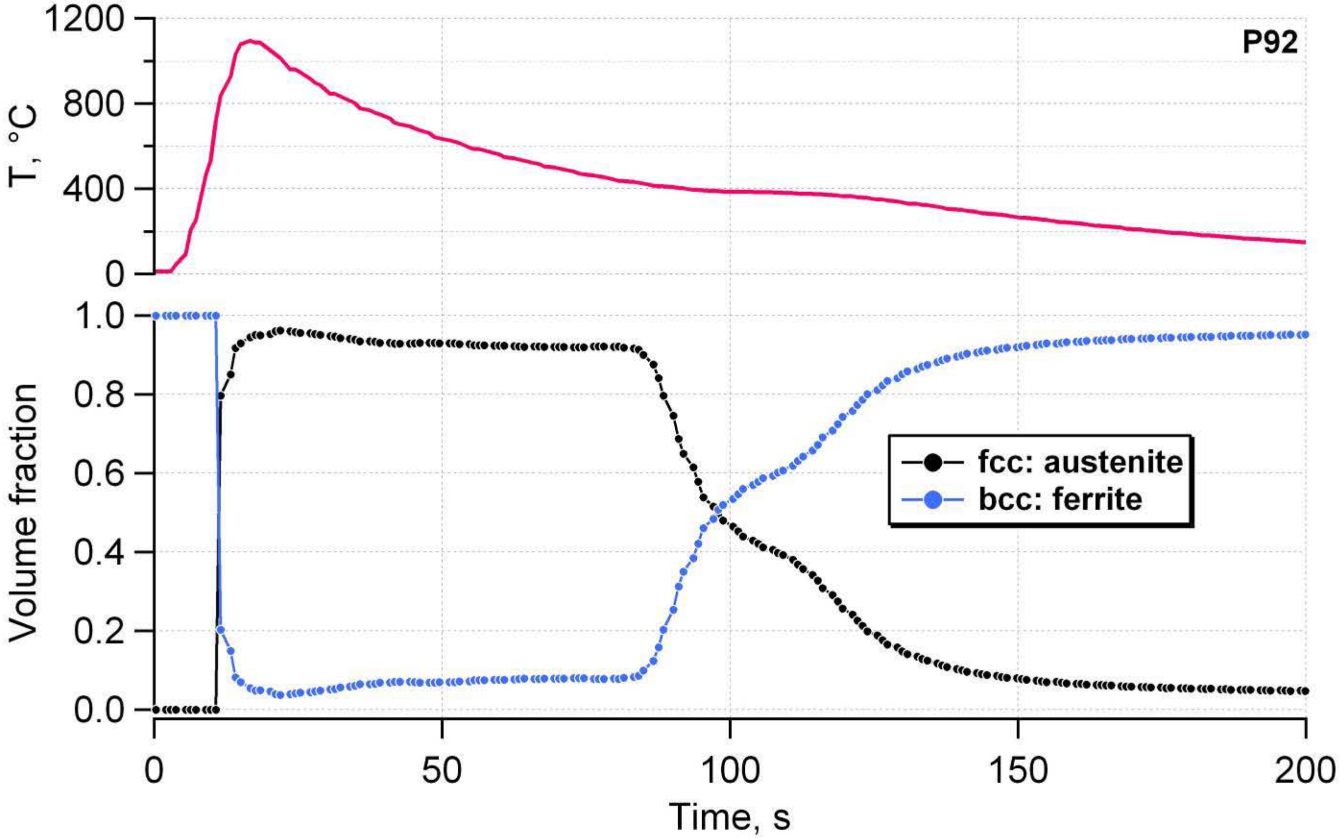
Welding Handbook, 8th Edition, Volume 1, AWS

- HAZ peak temperatures & times determine phase transformation behavior and influence precipitation

Diffraction experiments can capture the dynamics of transformation behavior

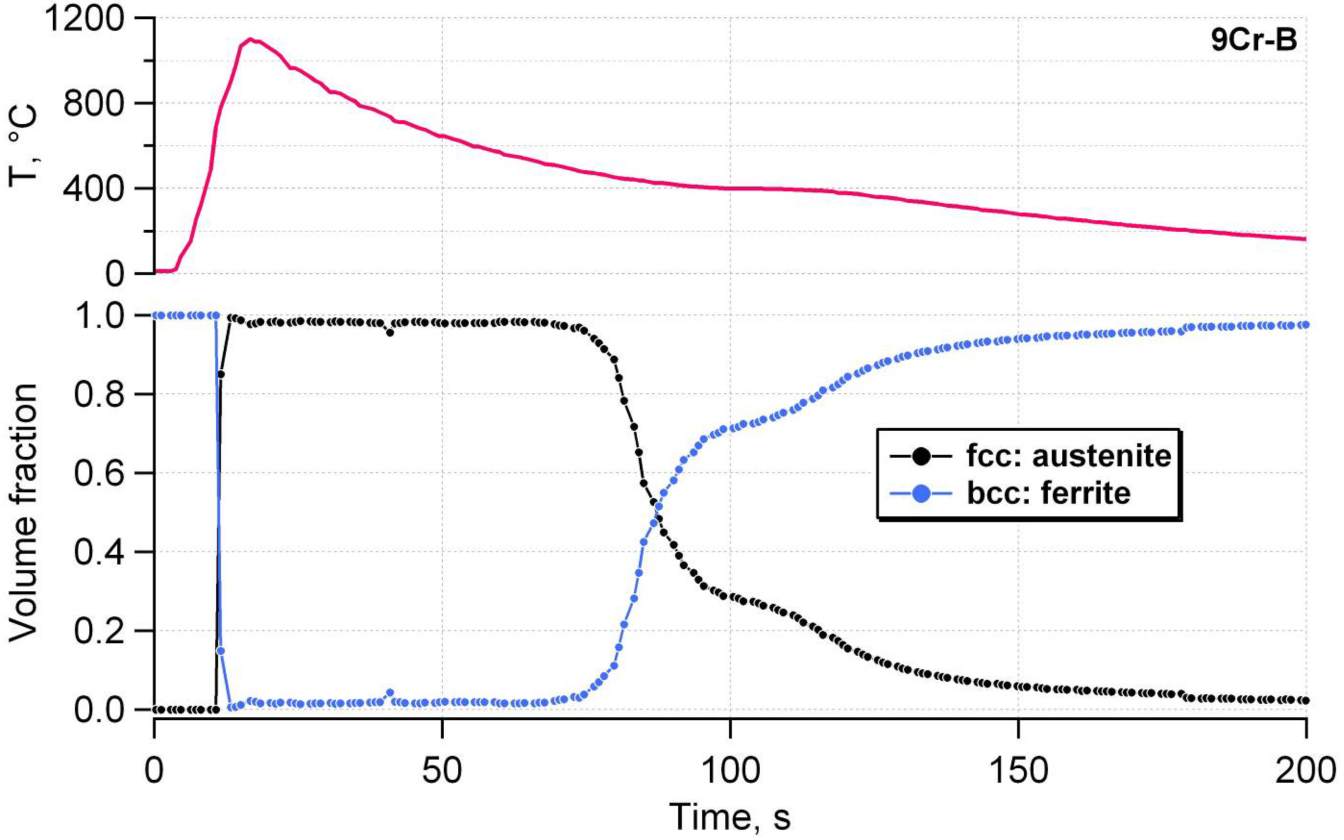


Detailed estimation of transformation behavior of commercial steel P92



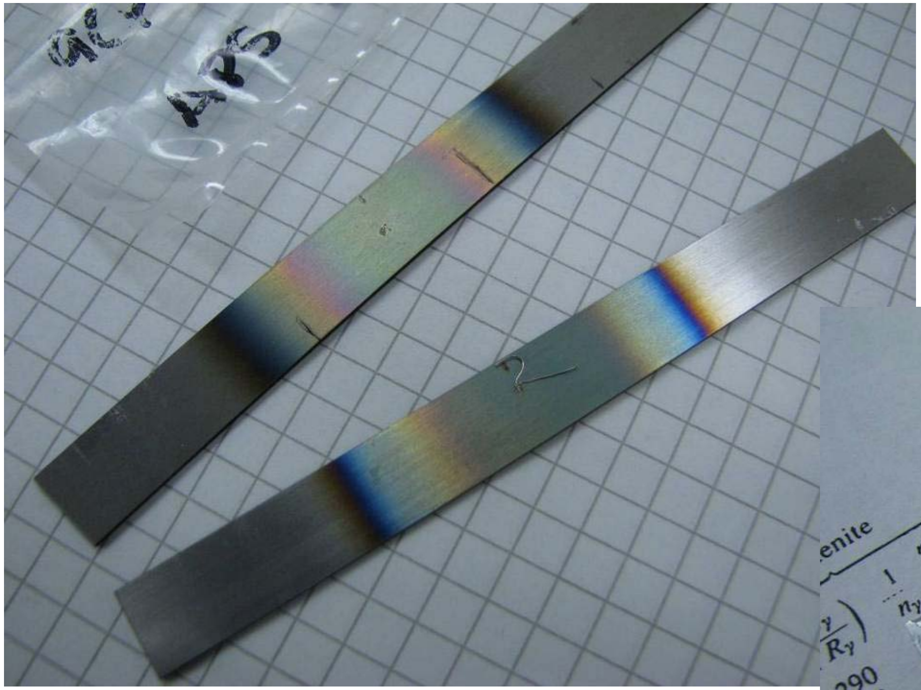
- Characteristic of transformations in Coarse-Grained HAZ

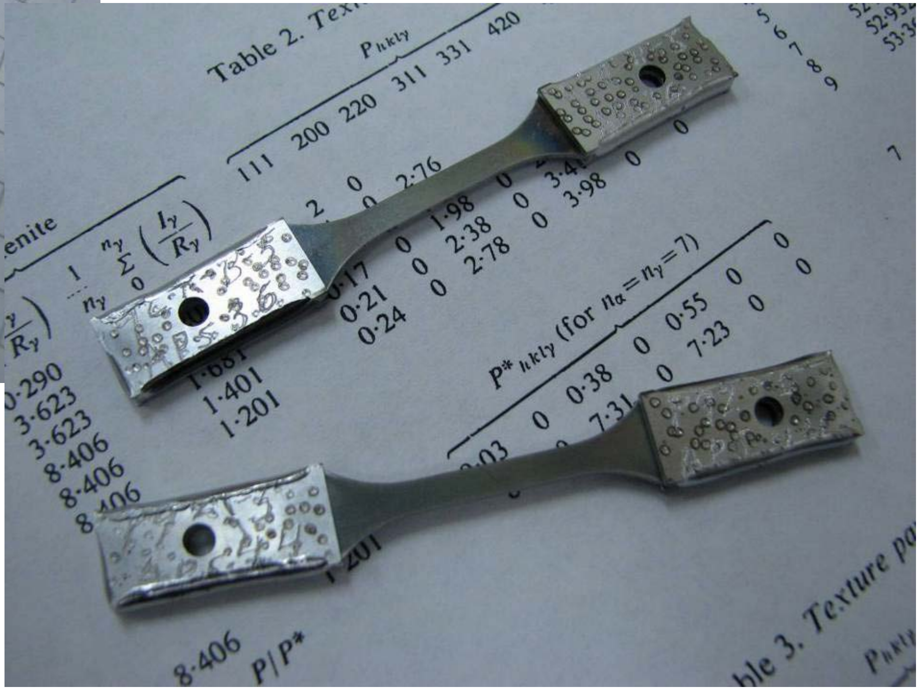
Detailed estimation of transformation behavior of Type-IV-resistant steel



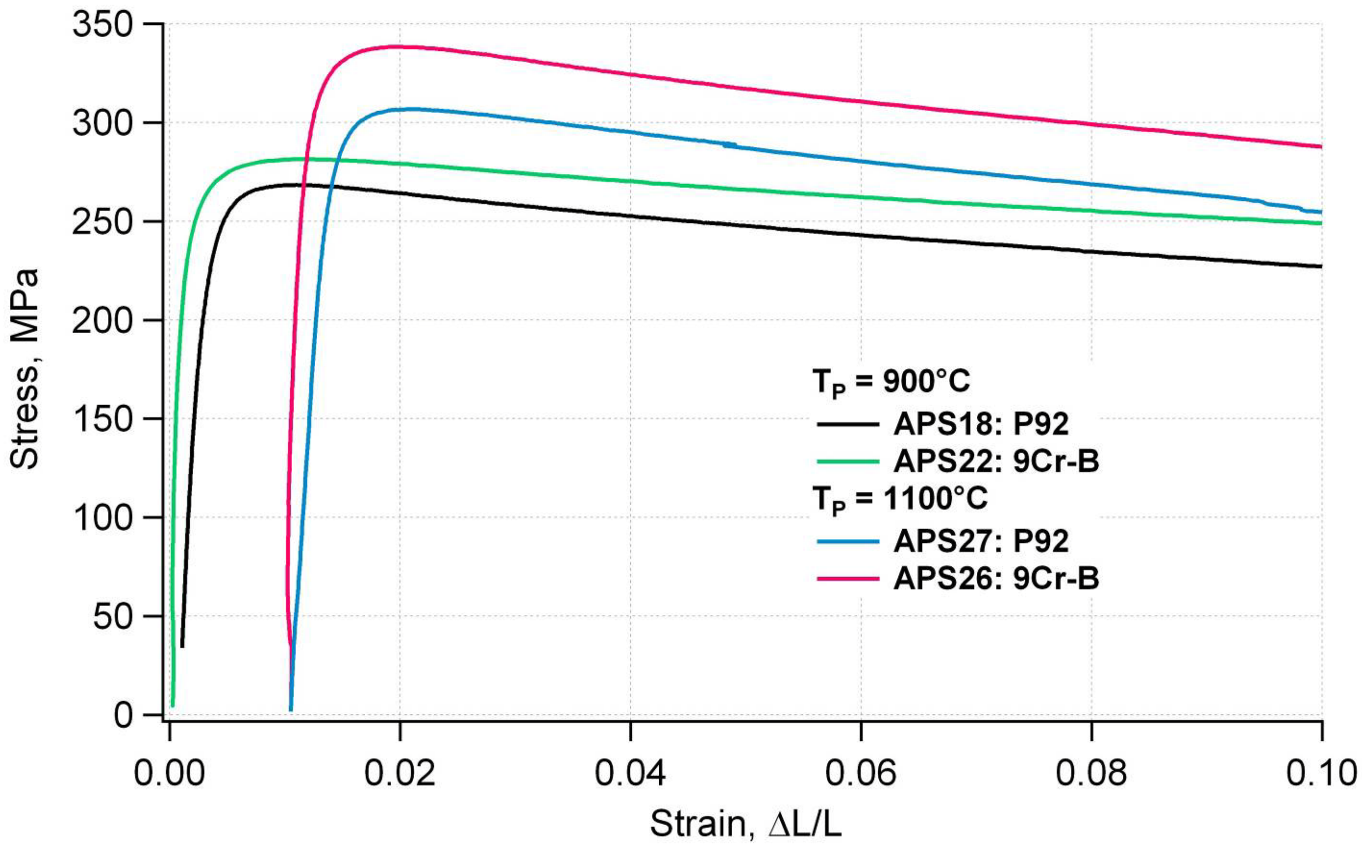
- Compared to P92 very little ferrite is retained
- Higher austenite fraction will produce more martensite for strengthening

Diffraction specimens were made into tensile-creep specimens



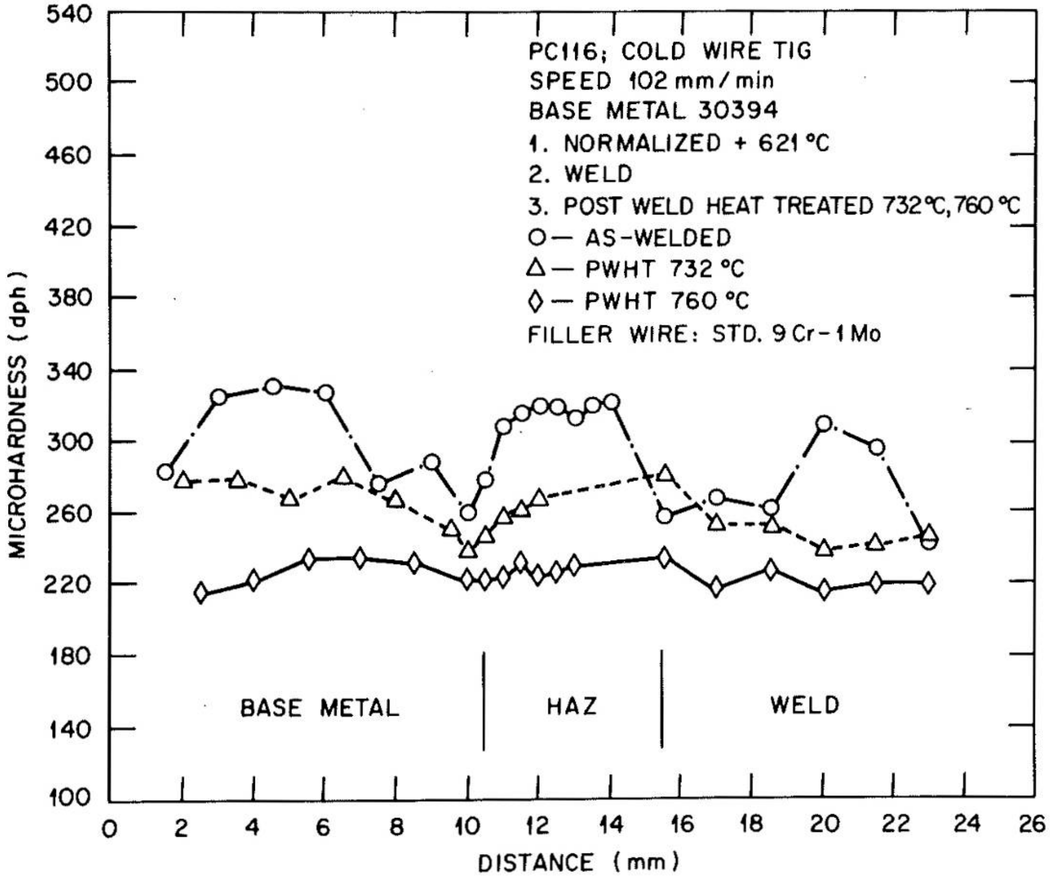


Tensile results 650°C



- Experimental steel has higher tensile strength than P92
- Creep tests are being prepared

Data from CRBR suggests modified temper-PWHT can improve resistance to Type IV



- Potential was never pursued due to closure of CRBR project
- Experiments to confirm/capitalize on behavior are in-progress

Modified temper-PWHT is being comprehensively revaluated

- Normalized plates were tempered at 600, 650, 700, 760, 800°C
- Welds made with 9Cr filler metal
- Pieces were PWHT at 760°C
- Metallography/hardness testing in progress
- Tensile/creep screening is planned

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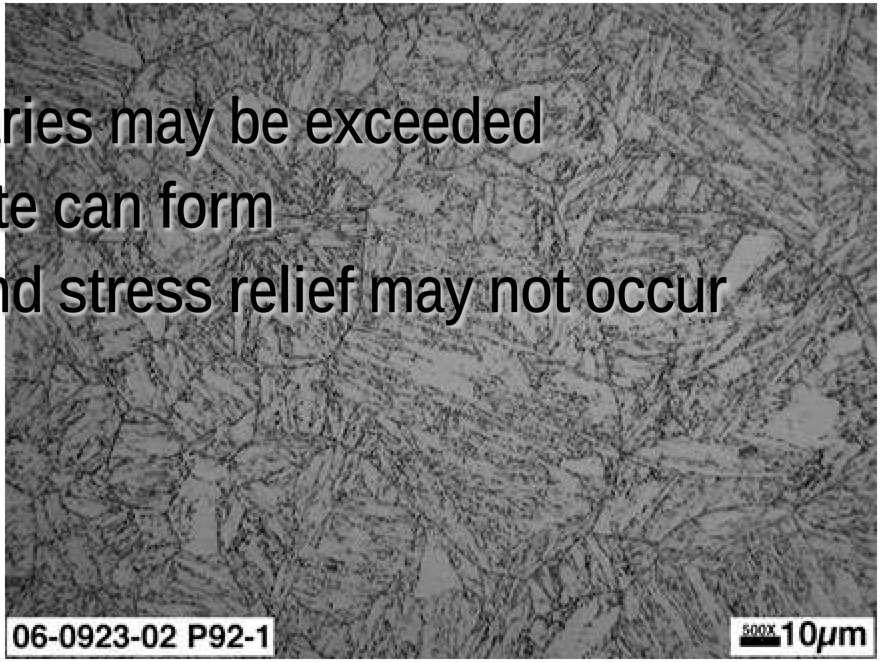
Specification of heat treatment temperatures is critical for developing the desired properties

- Temperature too low:
  - Thermal activation is too low for the desired annealing/softening
  - Diffusion is too slow for developing desired carbide distributions
- Temperature too high:
  - Critical phase boundaries may be exceeded
  - Untempered martensite can form
  - Expected softening and stress relief may not occur



Heat treatment is typically required for Cr-Mo steel components built to ASME Code

Until recently for 9Cr steels:

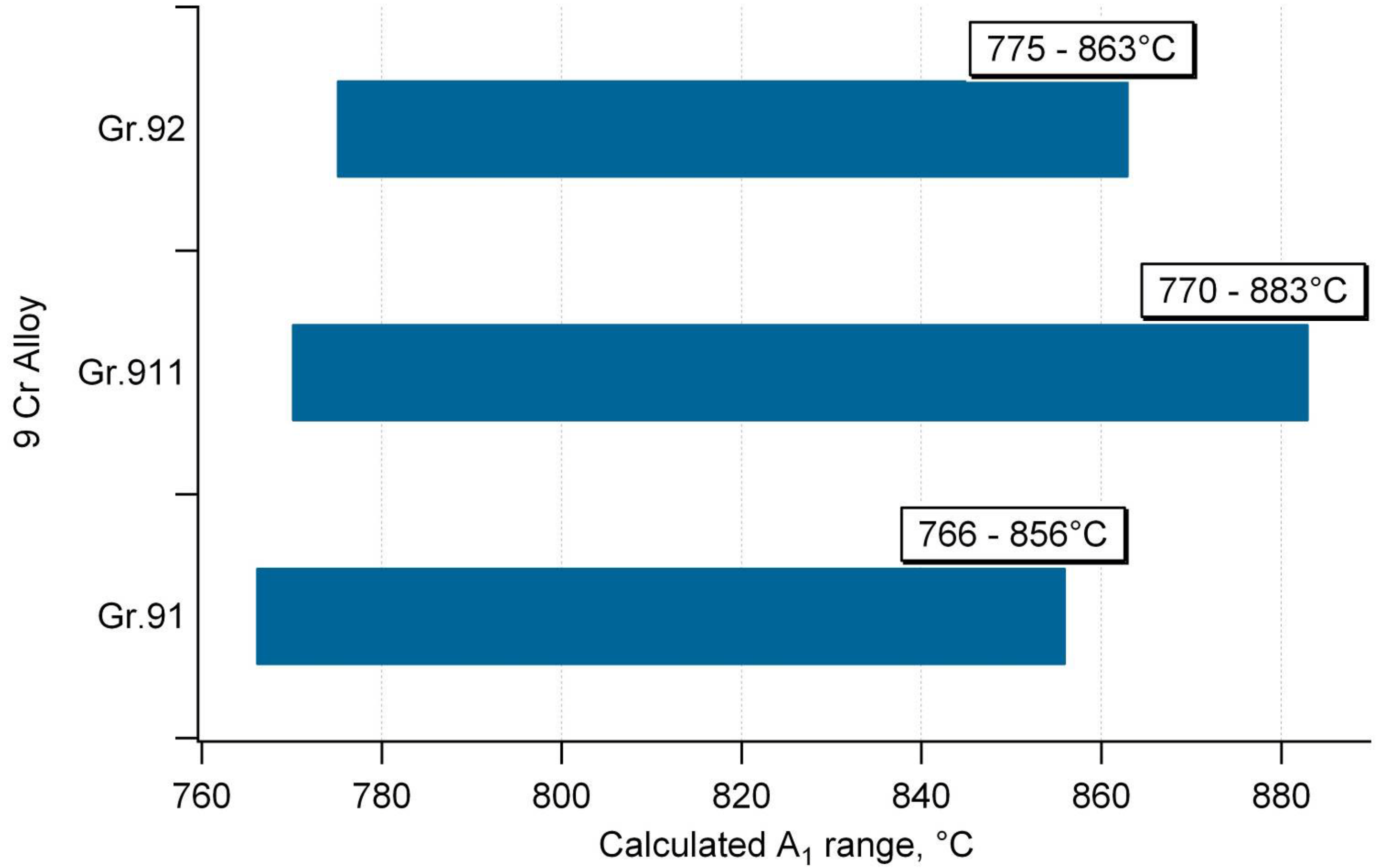
- Code specified:
  - 730°C min. for temper
  - 704°C min. for PWHT
- No maximum temperatures were specified
  - Expectation was that critical temperatures were not exceeded
- No comprehensive information about temperature limits was available
  - Fabricators may heat-treat at temperatures above minimums to minimize processing time and costs

Tempering/PWHT requirements are being rethought

Basic questions:

- How high is too high for tempering or PWHT?
- Are tempering/PWHT rules consistent with chemical composition specifications?
  - Critical transformation temperatures, like the lower ferrite $\rightarrow$ austenite, A_1, depend on steel composition

Calculated A_1 ranges for 9Cr steels based on ASTM specified chemistries



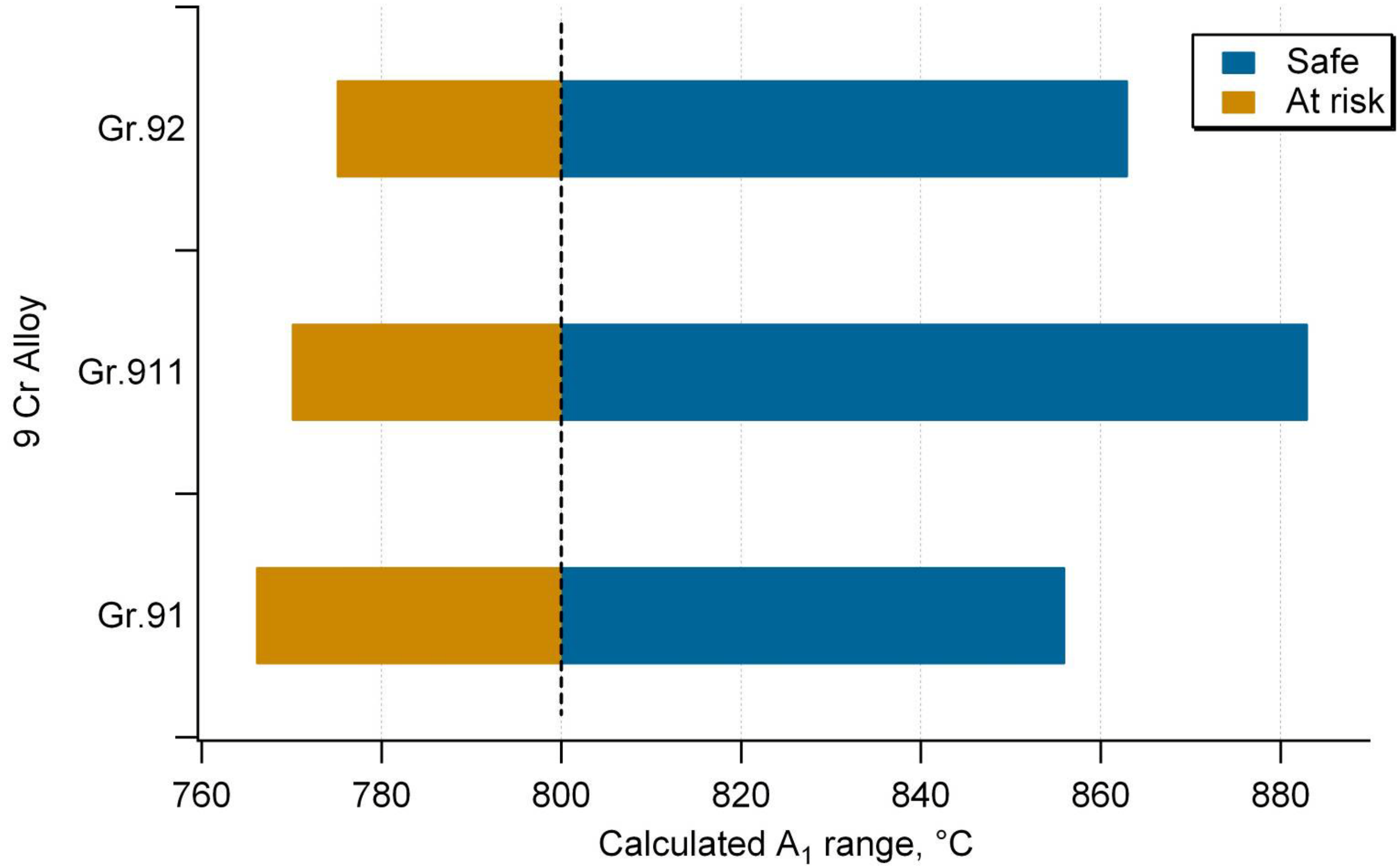
- A limit of 760°C would be reasonable for all 3 steels

Thermodynamic analysis contributed to revisions of tempering & PWHT rules

- Re: SA213, SA335, SA387

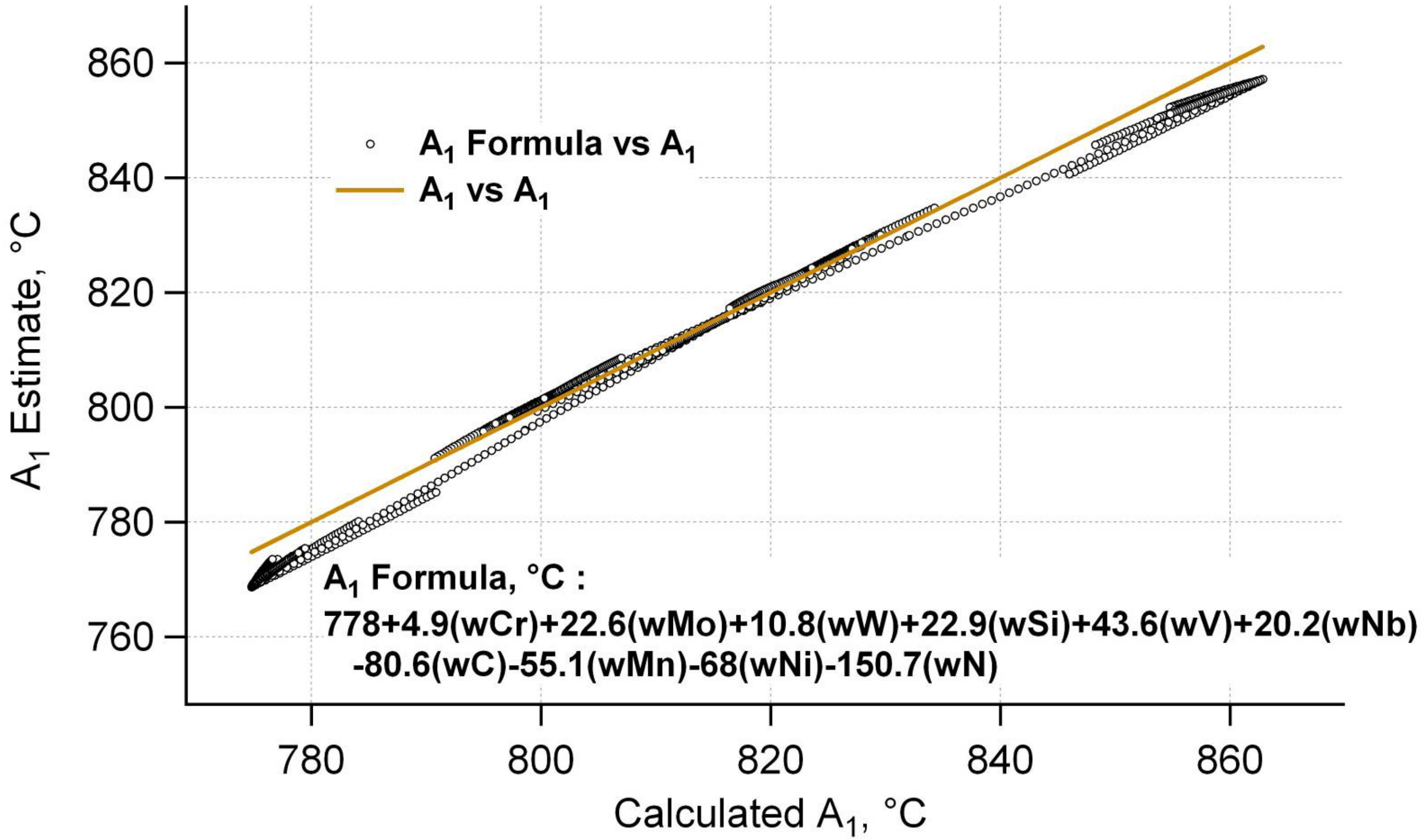
	Old	New
Normalize	1040°C min.	1040-1080°C
Temper	730°C min.	730-800°C
PWHT	704°C min.	730-775°C 790°C if 1 ≤ (Mn + Ni) < 1.5 800°C if (Mn + Ni) < 1

800°C limit still permits exceeding A_1 of some compositions in the ASTM spec.



- Alloys with A_1 < 800°C can form untempered martensite

Thermo results were reduced to simple linear formulas



- Formulas could be used as “rules” for heat treating

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Improving Performance of CSEF Steels

Highlights:

- Using advanced tools – like APS, ThermoCalc – to better understand high-performance alloys
  - Develop solutions to minimize/eliminate Type IV failure
- Using unique capabilities and fundamental understanding to assist ASME and manufacturers in better-informed use of CSEF steels and Ni-based alloys
  - Using computational thermodynamic analysis to define more robust alloy specifications
  - Supporting component design and reliability with testing and analysis of mechanical behavior

Milestones & Status:

- Initiate creep testing of specimens subjected to simulated heat-affected zone heat treatments during synchrotron diffraction.
  - 04/30/2010
  - Specimens are waiting for preparation of creep frames to be finalized
- Summarize in a technical report or a publication manuscript the initial evaluation of heat treatment procedures on microstructures and hardness distributions in 9 Cr steel weldments.
  - 09/30/2010
  - Should be met with combination of annual report & ASME/PVP conference paper
- Complete creep testing to ~8,000 hours on welded joints with modified heat treatment procedures.
  - 09/30/2011