BOILER MATERIALS FOR USC PLANT

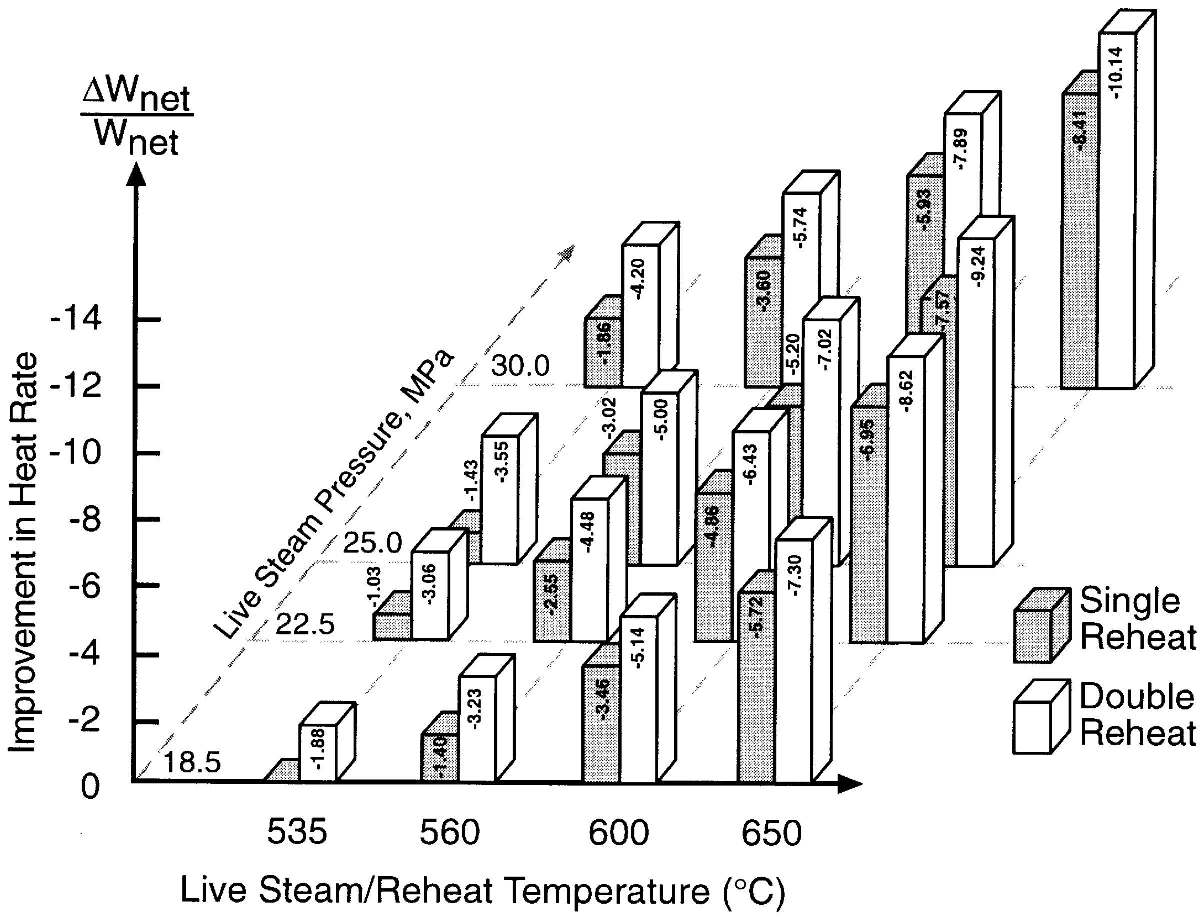
R. Viswanathan

DOE Project Manager: R. Romanosky/U. Rao

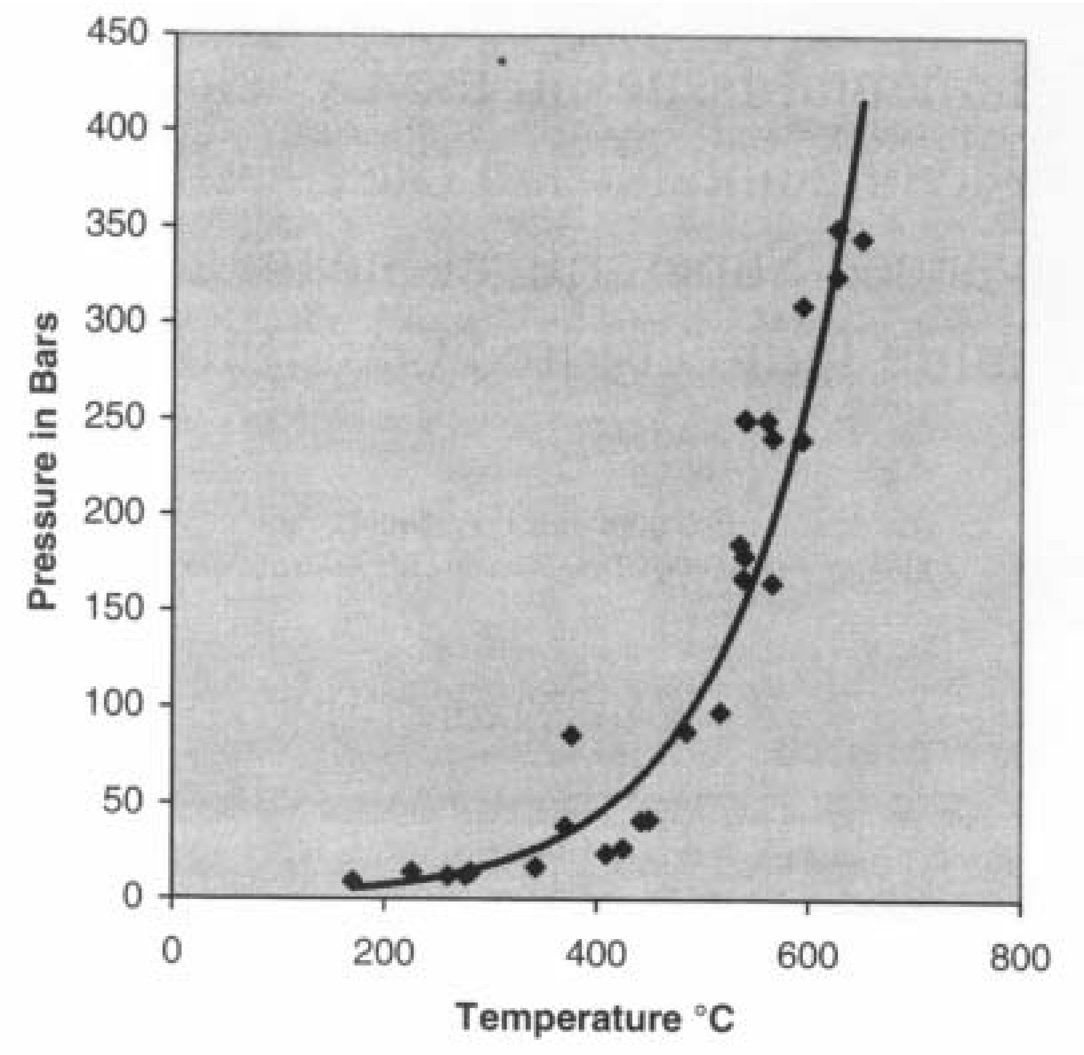
EIO Project Manager: R. Purgert

OCDO Project Manager: H. Johnson

Improvements in heat rate (efficiency) achieved by increasing steam temperature and pressure using single and double reheat cycles (Ref. 1), compared to the base case of 535ºC/18.5 MPa



Steam Turbine Pressure versus Temperature



EPRI

Current Situation of USC

- 1100°F (593°C)/4300 psi (30MPa) single reheat plants are SOA. About dozen plants exist in Europe and in Japan.
- The EU has an ambitious R&D project aimed at 1300°F(700°C)/5400 psi (37.5MPa) steam condition.
- Phase 1 - 6 yrs/21 million Euro/40 companies/10 countries has been completed. EU contributes 40%.
- Phase 2 - 4 yrs/11.2 million Euro/EU 50% started in January 1, 2002.
- Demo plant envisaged for 2007. Funding being sought.
- National programs in Germany.

Goals of the DOE/OCDO Project

The GOALS include:

- Identify advanced materials that achieve cost competitive, environmentally acceptable coal based electric power generation that includes the use of high sulfur coals;
- Enable domestic boiler manufacturers to globally compete for the construction and installation of high efficiency coal fired power plants.

Specific Objectives of the USC Materials Project

The OBJECTIVES of the Ultra Supercritical Materials Program are to:

- Identify materials performance issues that limit operating temperatures and thermal efficiency of coal-fired electricity generating plants;
- Identify improved alloys, fabrication processes and coating methods that will permit boiler operation of steam temperature up to 760ºC or 1400ºF and steam pressures up to 5500 psi;

Specific Objectives of the USC Materials Project
(cont'd.)

- Work with alloy developers, fabricators, equipment vendors and power generators to develop cost targets for the commercial deployment of alloys and processes developed;
- Define issues impacting designs that can permit power generation at temperatures greater than or equal to 870ºC or 1600ºF;
- Lay the groundwork for ASME Code approval.

Benefits of the USC Materials Project

This program will have an impact on

- Ultrasupercritical coal combustion systems, ensuring fuel flexibility and coal based power generation.
- Integrated gasification combined cycle plants
- Hybrid cycles incorporating partial gasification and fluid bed combustion
- Gasification fuel-cell/turbine systems.
- The near term benefits could solve high-temperature materials problems in present power generation systems.
- The long term benefit would be the development of new high temperature materials capable of providing for higher efficiency cycles critical to the success of the Vision 21 concept. Higher efficiencies result in reduced fuel costs, BOP costs and emissions.

Schedule and Funding

- Duration: October 2001 – September 2006
- Funding:
  - USDOE/National Energy Technology Labs $15.2MM
  - Ohio Coal Development Office/Ohio Dept. of Development $ 2.0MM
  - Cost share by members $ 2.7MM

The Tasks

- Task 1 Conceptual Design—EPRI/Others
- Task 2 Mechanical Properties—EPRI/ORNL
- Task 3 Steamside Oxidation—B&W
- Task 4 Fireside Corrosion—Foster Wheeler
- Task 5 Welding Development—Alstom
- Task 6 Fabricability—B&W
- Task 7 Coatings—Alstom
- Task 8 Design Data Codes—Alstom
- Task 9 Project Management—EIO/EPRI

Estimated Plant Efficiencies for Various Steam Cycles (Ref. P. Weitzel and M. Palkes)*

Description	Cycle	Reported at European Location (LHV/HHV)	Converted to U.S. Practice(4) HHV
Subcritical	16.8 MPa/538ºC/538ºC		37
Supercritical	24.5 MPa/565ºC/565ºC/565ºC(3)		40.9
ELSAM (Nordjyland 3)	28.9 MPa/580ºC/580ºC/580ºC	47/44	42
Thermie	38 MPa/700ºC/720ºC/720ºC	50.2/47.7	46.0
DOE/OCDO USC Project	38.5 MPa/760ºC/760ºC 38.5 MPa/760ºC/760ºC/760ºC		46.5 47.5 - 48

3. Eastern bituminous Ohio coal.
4. Reported European efficiencies are generally higher compared U.S. due to differences in reporting practice (LHV vs HHV), coal quality, auxiliary power needs, condenser pressure and ambient temperature and many other variables. Numbers in this column for European project numbers are adjusted for U.S. conditions to facilitate comparison.

Plant Efficiency (Europe vs US)

- Boiler efficiency
  - Presentation in LHV in Europe gives higher value compared to HHV in USA (2% difference)
  - Lower S content in European coal permits lower flue gas exit temperature (105ºC (221ºF) in Europe vs 133ºC (272ºF) in US
- Turbine Efficiency
  - Colder latitudes and cold sea water cooling permits lower condenser back pressure in Europe (0.62" HgA in Europe vs 2.0" Hg in US) (0.7% difference)
  - Number of reheat stages: double vs single (1.7%)
- Auxiliary Power
  - Lower auxiliary power consumption in Europe

These factors can increase heat rate for US plant by as much as 1055kJ/kWh or 1000 Btu/kWh or 3-5% difference in efficiency.

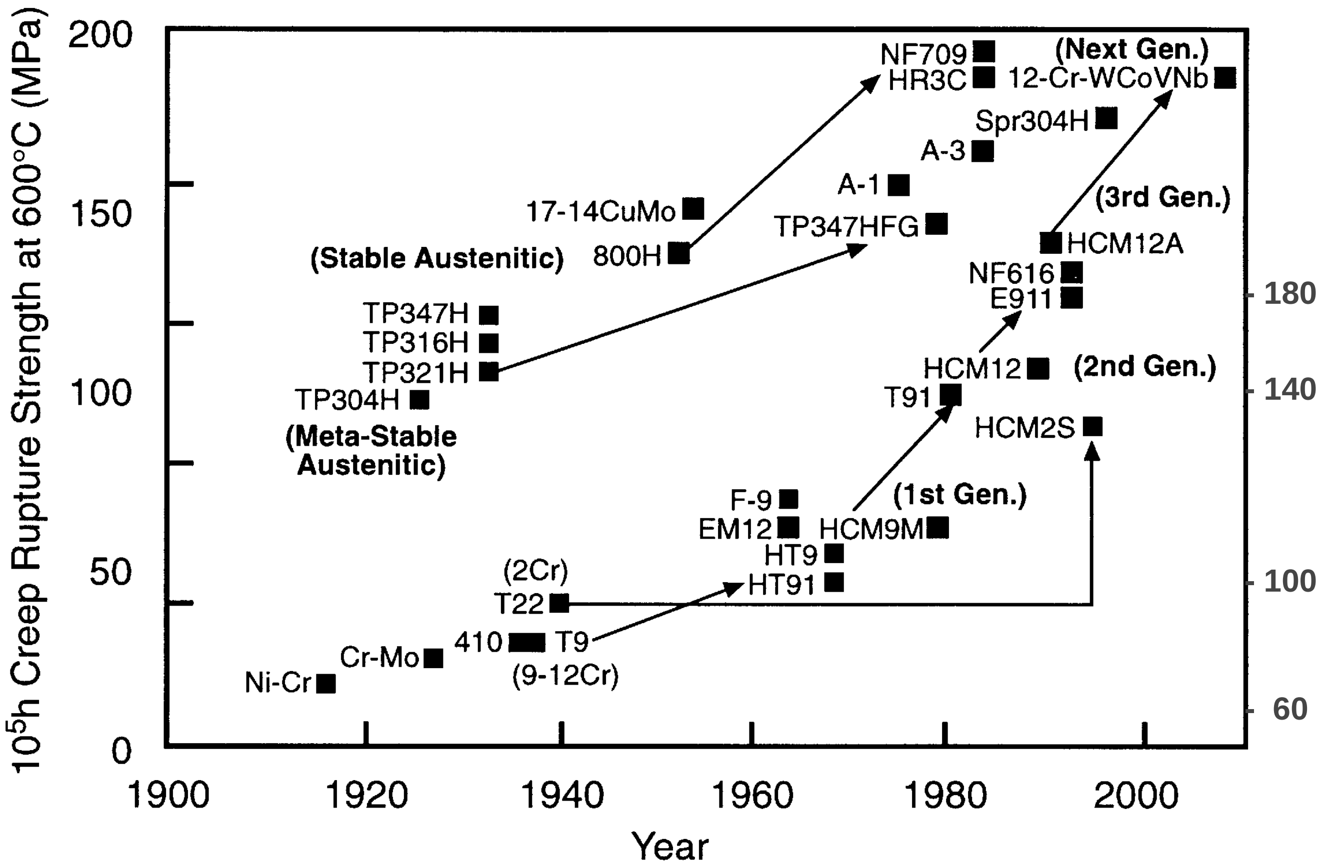
Conclusions

- If the USC plant efficiency can be improved to 45 to 48%, then the USC Total Plant Cost can be allowed to be 12 to 15% higher at the same cost of electricity as a subcritical PC Plant
  - **Based on EPRI TAG financial parameters, 20 year plant life, 80% capacity factor, and a coal cost of $1.50/MMBtu**
- USC BOP cost can be 13 to16% lower
  - **Smaller coal handling, pollution control, and other BOP costs for the same net plant output**
- USC Boiler/Steam Turbine cost can be allowed to be 40 to 50% higher
- Emissions are reduced by 15 to 22%

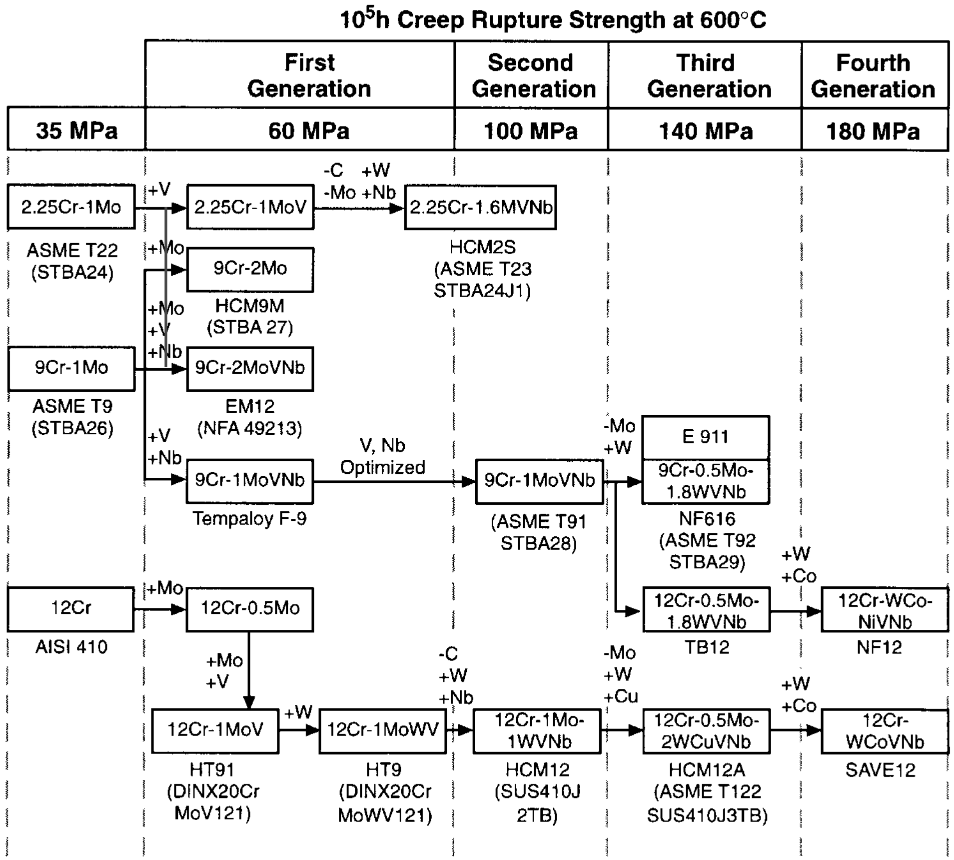
Issue Related to Three Major Boiler Components Are Being Addressed

- Waterwalls
- Superheater/reheater tubing
- Headers and piping

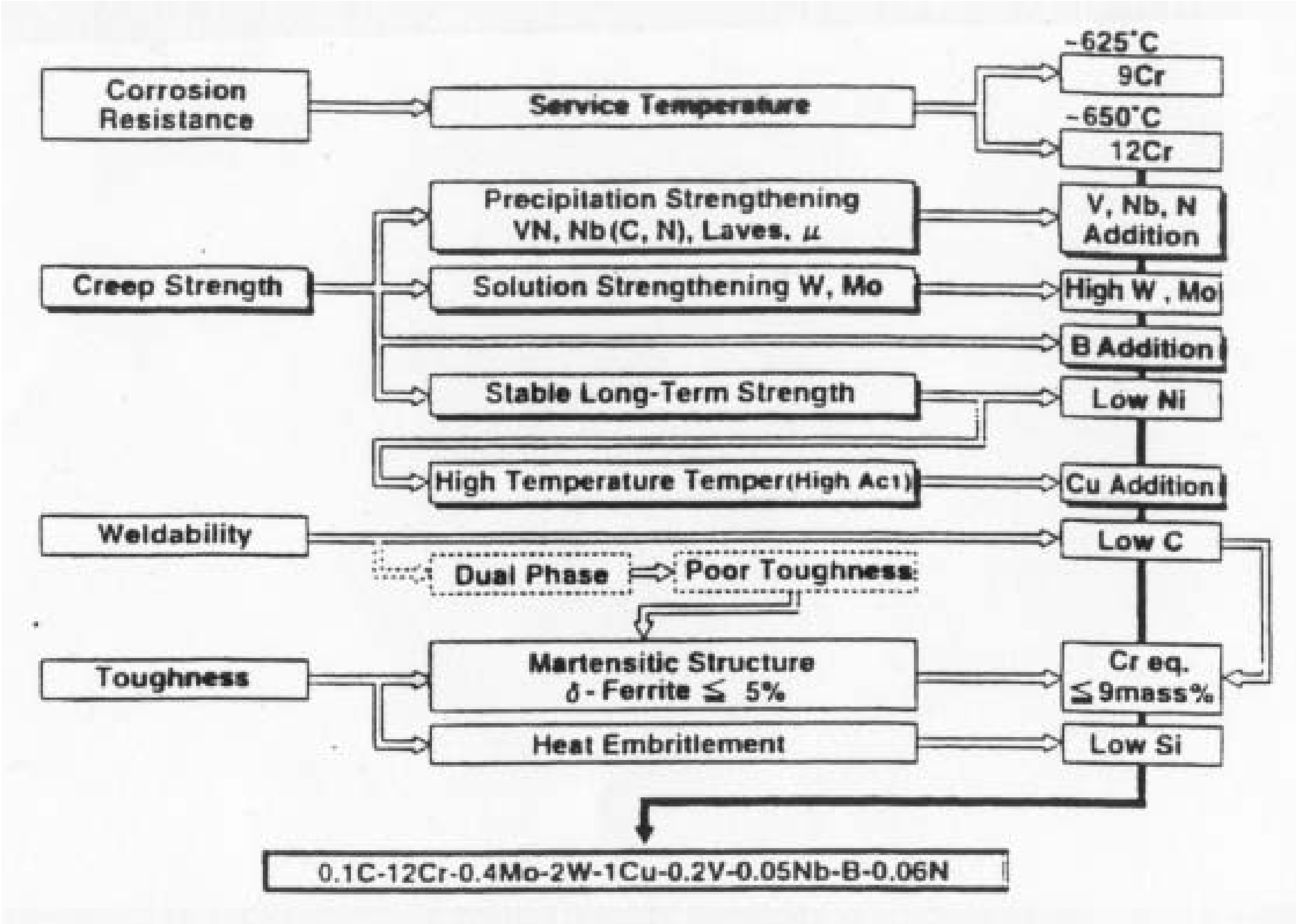
Historic Evolution of Materials in Terms of Increasing Creep Rupture Strength



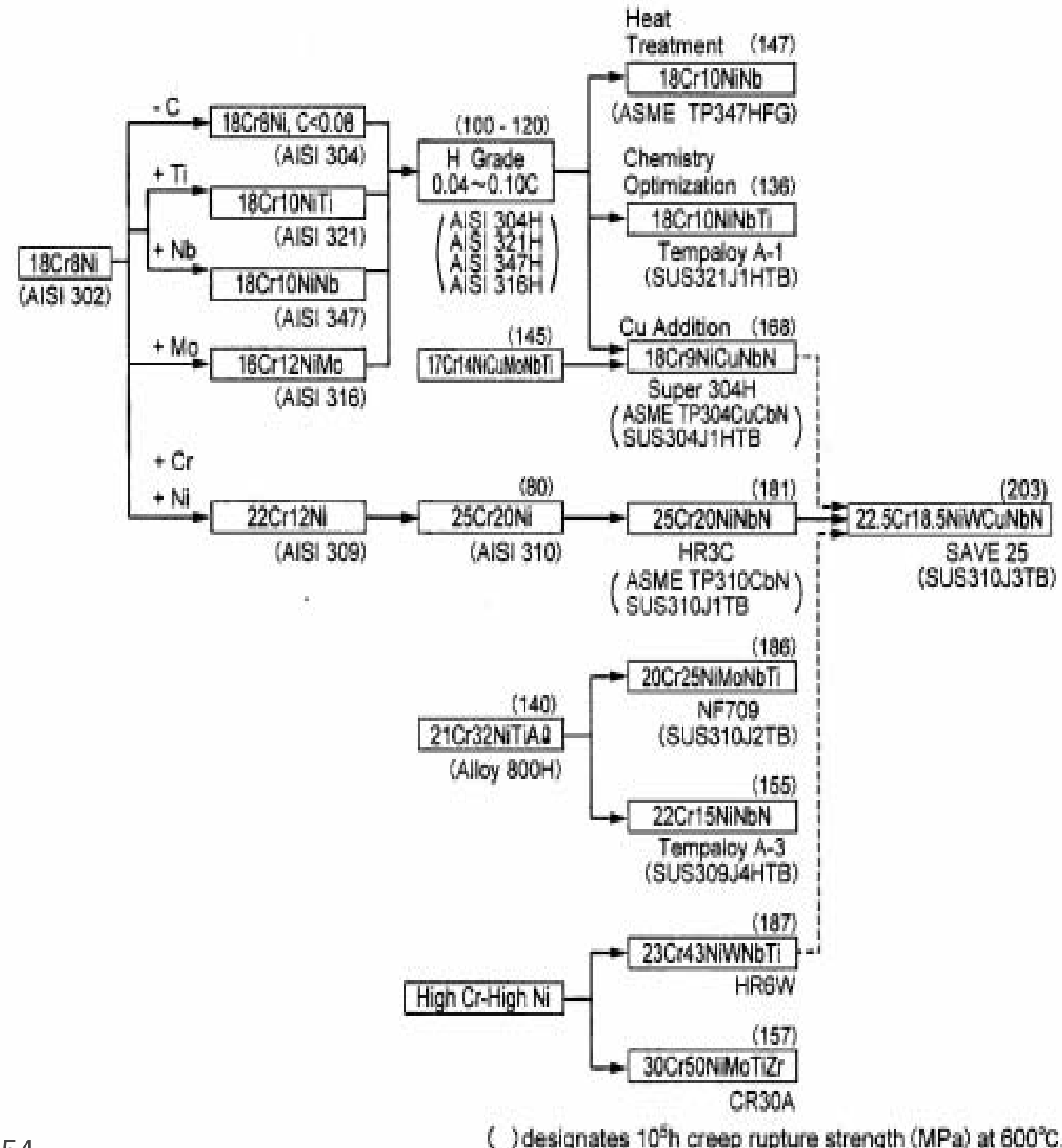
Evolution of Ferritic Steels for Boilers



Alloy Design for HCM12A



Development Progress of Austenitic Steels for Boiler



Comparison of Allowable Stresses of Ferritic Steels for Boiler

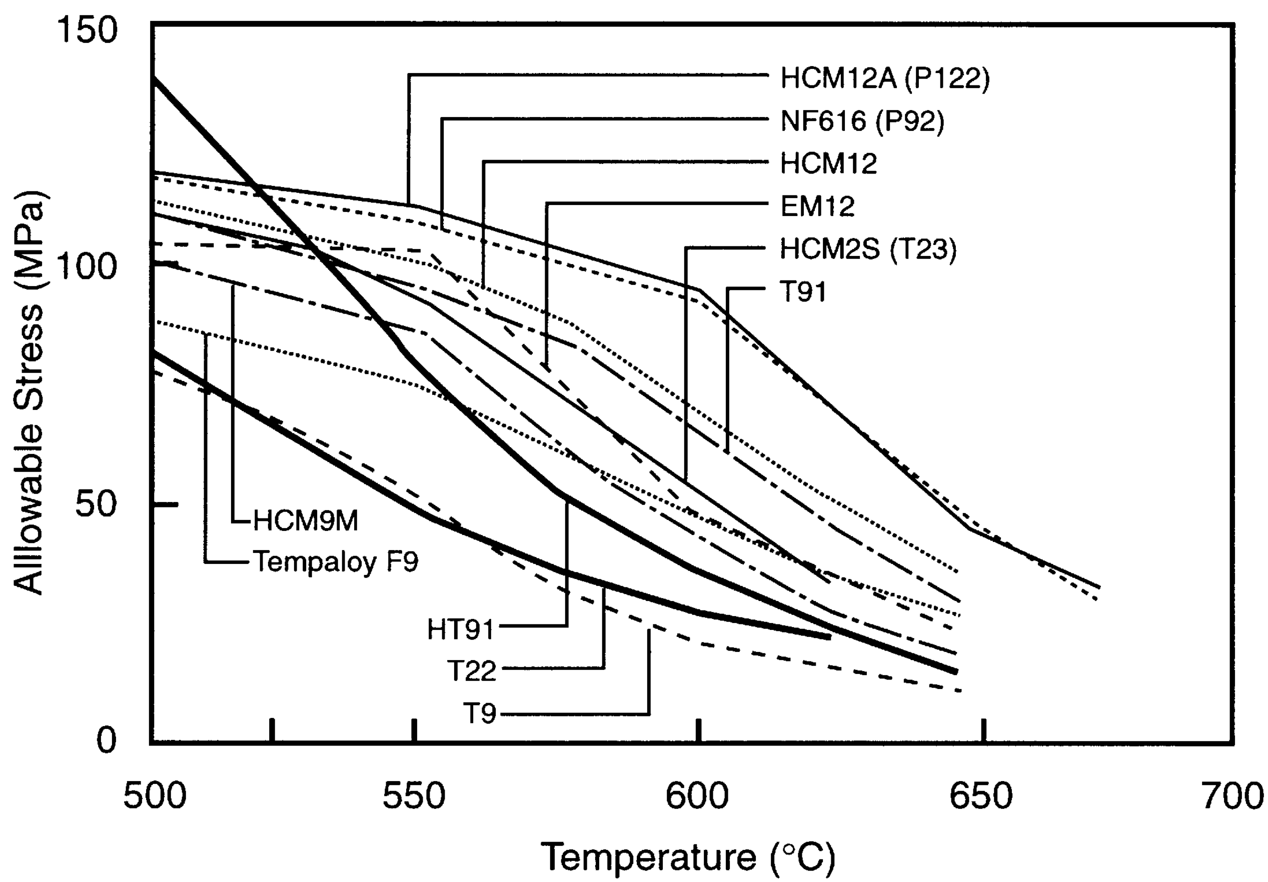
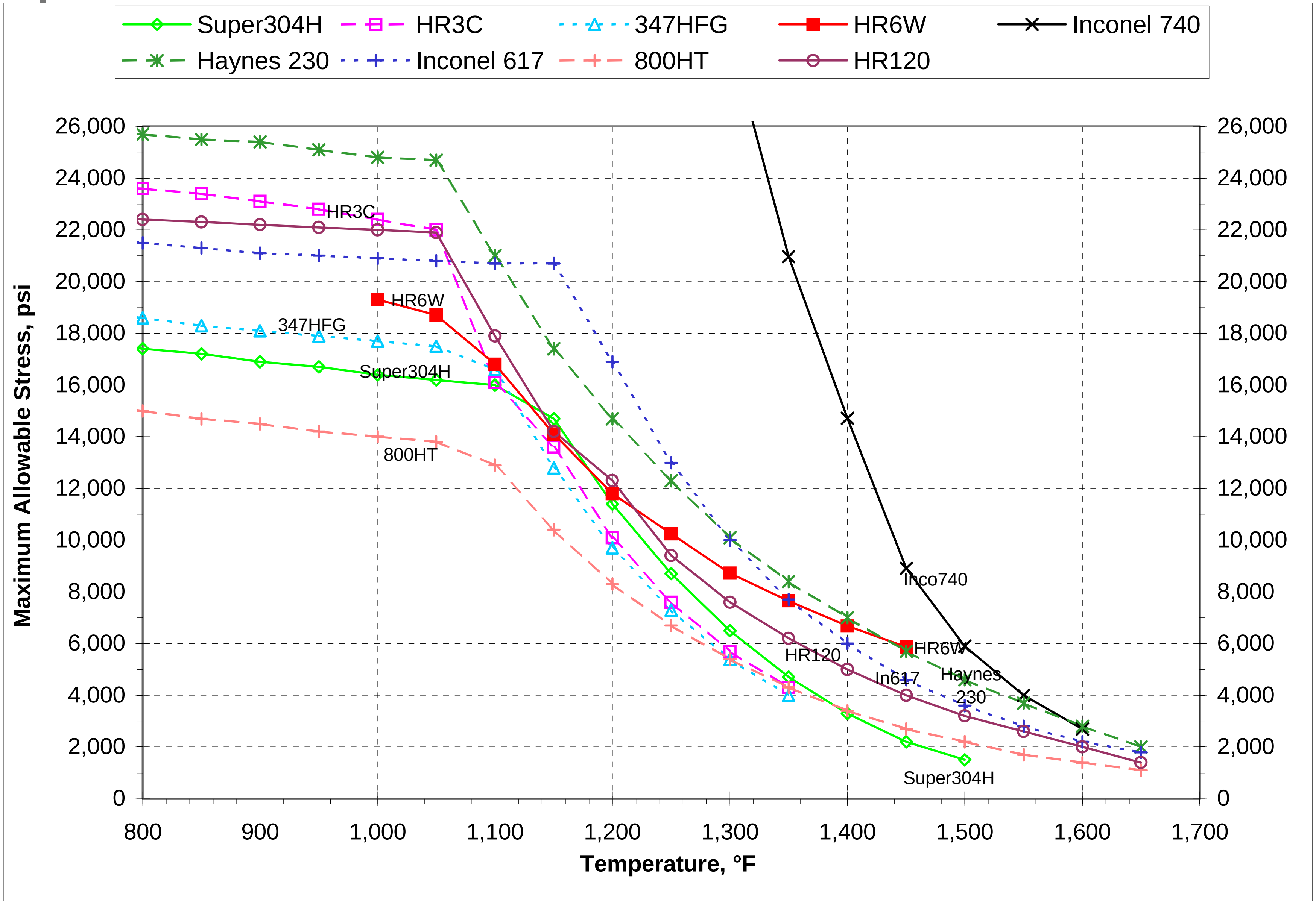


Figure 2: Preliminary Allowable Stress Levels



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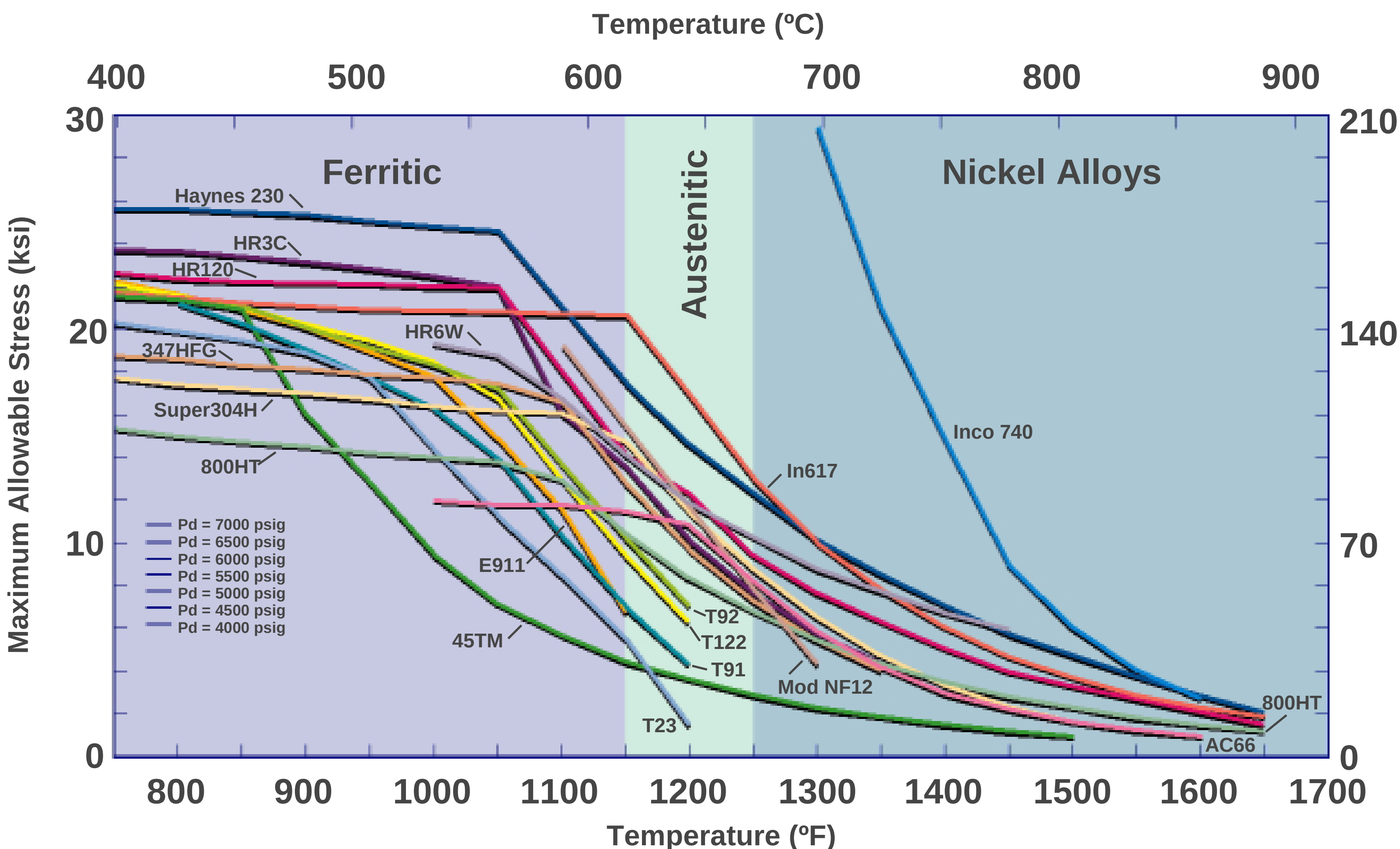
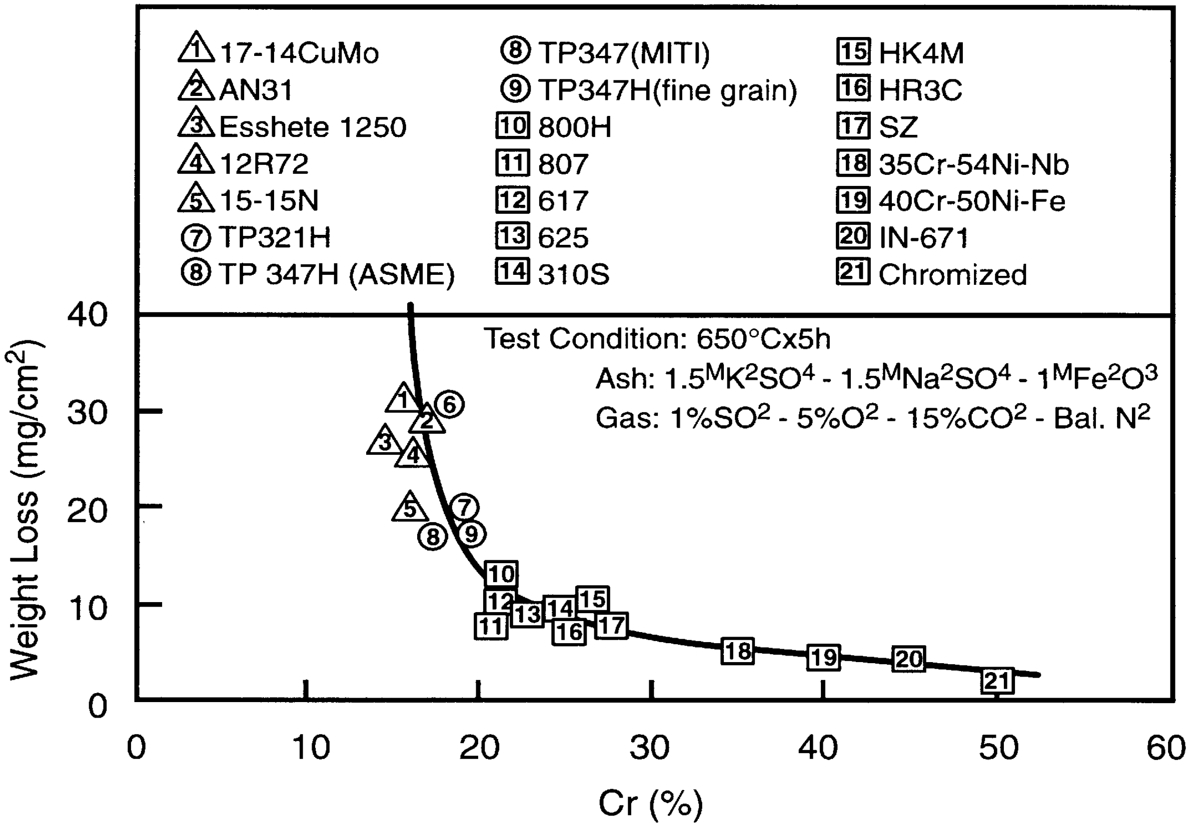
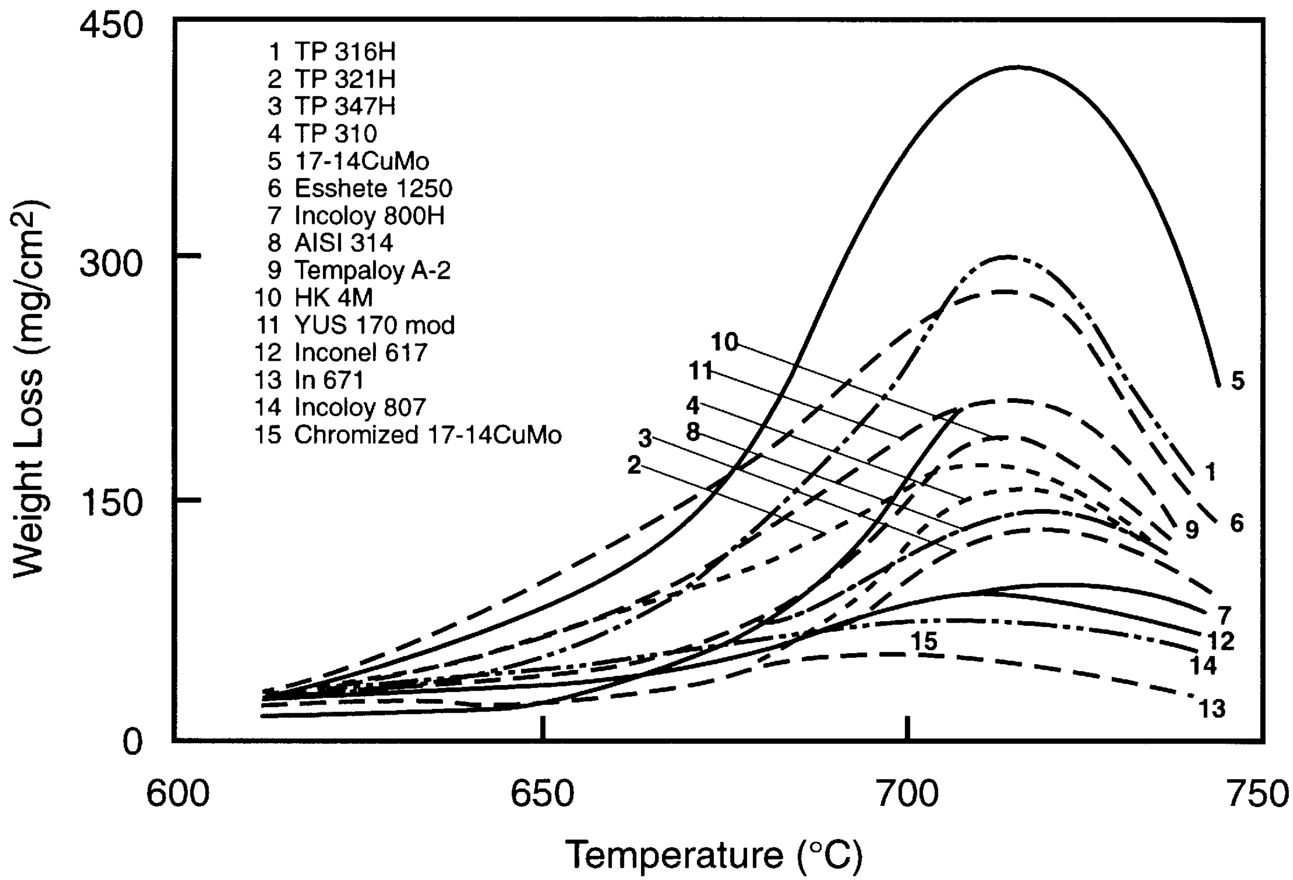


Relationship Between Hot-Corrosion Weight Loss and Chromium Content for Various Alloys



Note saturation of Cr effect above 30%

Comparison of Fire-side Corrosion Resistance of Various Alloys



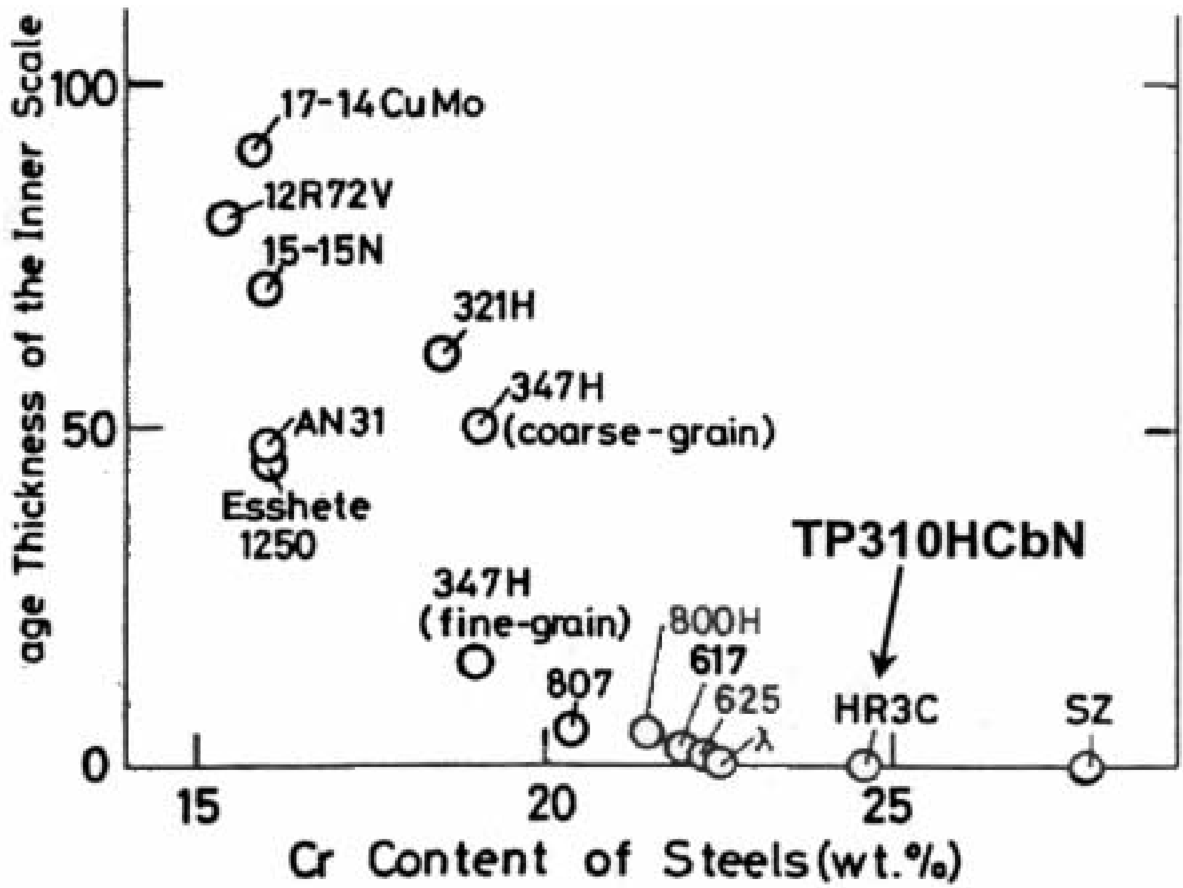


Fig. 4 Laboratory test results of high-Cr, high-Ni steels and alloys reacted with 100% steam at 700°C (1292°F) for 1000 h[9].

Conclusions from Design Study

- The feasibility of designing an ultra supercritical 750W boiler operating at 732/760ºC(1350/1400ºF) and 35 MPa (5000 psig) with existing material technology is encouraging. This design would be capable of achieving a net plant efficiency of 45.5% HHV based on US design practice and as high as 50.5% when expressed in European format with alternative European boundary conditions.
- Throttle temperature increase is much more advantageous than throttle pressure increase for improvement of efficiency at minimal cost impact.
- The original project goal for throttle pressure and temperature produced excessively thick pressure parts. A 50ºF reduction to 732ºC (1350ºF) in temperature from the original goal was required to obtain a design that would prove acceptable for current boiler operating expectations. Reheat inlet temperature is 760ºC (1400ºF).

Conclusions from Design Study (cont'd.)

- Nickel based super alloys are required for major portions of the superheater and reheater. Economizer sections can be fabricated with currently available carbon steel materials. Enclosure walls can be fabricated from SA213T23 material. T92 is an alternative.

- The USC boiler has a capital cost approximately 28% higher than the comparable subcritical boiler. This is well below the 40% increase permitted by EPRI to breakeven on a cost of electricity basis. It was noted that unknowns in fabrication and erection costs with the new materials could skew the results somewhat.

Progress To Date

- Conceptual design and economic analysis have been completed.
- Materials and coatings selection and procurement is nearly completed.
- Equipment calibration and testing, specimen design and other preliminaries for corrosion and mechanical tests are complete.
- Utility sites for field tests have been identified.
- Limited mechanical tests have been started at ORNL.

Progress To Date (cont'd.)

- Topical Reports have been issued.
  - Conceptual Design and Material Solution
  - Economic Analysis
  - SOA of Coatings
  - SOA of Steamside Oxidation
  - 4-volume report on materials nearly complete at ORNL