BOILER MATERIALS FOR ULTRASUPERCRITICAL COAL POWER PLANTS

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Abstract

The U.S. Department of Energy (DOE) and the Ohio Coal Development Office (OCDO) have recently initiated a project aimed at identifying, evaluating, and qualifying the materials needed for the construction of the critical components of coal-fired boilers capable of operating at much higher efficiencies than current generation of supercritical plants. This increased efficiency is expected to be achieved principally through the use of ultrasupercritical steam conditions (USC). A limiting factor in this can be the materials of construction. The project goal is to assess/develop materials technology that will enable achieving turbine throttle steam conditions of 760^{o}C (1400^{o}F)/35 MPa (5000 psi). This goal seems achievable based on a preliminary assessment of material capabilities. The project is further intended to build further upon the alloy development and evaluation programs that have been carried out in Europe and Japan. Those programs have identified ferritic steels capable of meeting the strength requirements of USC plants up to approximately 620^{o}C (1150^{o}F) and nickel-based alloys suitable up to 700^{o}C (1300^{o}F). In this project, the maximum temperature capabilities of these and other available high-temperature alloys are being assessed to provide a basis for materials selection and application under a range of conditions prevailing in the boiler. This report provides a quarterly status report for the period of July 1 to September 30, 2005.

Table of Contents

Executive Summary

A. Project Objective

The principal objective of this project is to develop materials technology for use in ultrasupercritical (USC) plant boilers capable of operating with 760°C (1400°F), 35 MPa (5000 psi) steam.

B. Background and Relevance

In the 21st century, the world faces the critical challenge of providing abundant, cheap electricity to meet the needs of a growing global population while at the same time preserving environmental values. Most studies of this issue conclude that a robust portfolio of generation technologies and fuels should be developed to assure that the United States will have adequate electricity supplies in a variety of possible future scenarios.

The use of coal for electricity generation poses a unique set of challenges. On the one hand, coal is plentiful and available at low cost in much of the world, notably in the U.S., China, and India. Countries with large coal reserves will want to develop them to foster economic growth and energy security. On the other hand, traditional methods of coal combustion emit pollutants and CO_2 at high levels relative to other generation options. Maintaining coal as a generation option in the 21st century will require methods for addressing these environmental issues.

This project has established a government/industry consortium to undertake a five-year effort to evaluate and develop of advanced materials that allow the use of advanced steam cycles in coal-based power plants. These advanced cycles, with steam temperatures up to 760°C, will increase the efficiency of coal-fired boilers from an average of 35% efficiency (current domestic fleet) to 47% (HHV). This efficiency increase will enable coal-fired power plants to generate electricity at competitive rates (irrespective of fuel costs) while reducing CO_2 and other fuel-related emissions by as much as 29%.

Success in achieving these objectives will support a number of broader goals. First, from a national prospective, the program will identify advanced materials that will make it possible to maintain a cost-competitive, environmentally acceptable coal-based electric generation option. High sulfur coals will specifically benefit in this respect by having these advanced materials evaluated in high-sulfur coal firing conditions and from the significant reductions in waste generation inherent in the increased operational efficiency. Second, from a national prospective, the results of this program will enable domestic boiler manufacturers to successfully compete in world markets for building high-efficiency coal-fired power plants.

The project is based on an R&D plan developed by the Electric Power Research Institute (EPRI) that supplements the recommendations of several DOE workshops on the subject of advanced materials. In view of the variety of skills and expertise required for the successful completion of the proposed work, a consortium that includes EPRI and the major domestic boiler manufacturers (Alstom Power, Babcock and Wilcox (a division of McDermott Technologies Inc.), Foster Wheeler, Riley Power Inc., and Oak Ridge National Labs) has been developed.

C. Project Tasks

The project objective is expected to be achieved through 9 tasks as listed below:

Task 1. Conceptual Design and Economic Analysis
Task 2. Mechanical Properties of Advanced Alloys
Task 3. Steamside Oxidation Resistance
Task 4. Fireside Corrosion Resistance
Task 5. Welding Development
Task 6. Fabricability
Task 7. Coatings
Task 8. Design Data and Rules
Task 9. Project Integration and Management

D. Major Accomplishments during the Quarter

- Long term creep rupture testing of the SAVE12 base metal began this month..
- Long term creep rupture test matrix for the HR6W tubing was completed this month.
- Low cycle fatigue testing was started on Inconel 740.
- Short-term cross-weld creep-rupture testing has been completed on a 5/8" thick Inconel 740 plate welded with both 740 and 263 filler metal.
- Pressurized creep testing of tube U-bends, to evaluate coldwork effects, were completed on the HR6W tube bend and two Haynes 230 bends.
- Steam side oxidation evaluation of the specimens removed following the second exposure at 800^{o}C was completed and the third exposure at 800^{o}C was conducted and the evaluation of these specimens was begun.
- The effect of ID shot blasting on the steamside oxidation of SUPER304H and 347HFG was evaluated and suggest that shot blasting is effective in reducing the exfoliation experienced by these materials.
- Results of the metallographic examination of the superheater/reheater fireside corrosion samples for carburization were incorporated into the wastage data.

- Much work was completed for the air cooled fireside corrosion probes including:
  - Fabrication and mechanical assembly of the probe retraction mechanisms for all three host sites have been completed.
  - Data acquisition, instrumentation and control systems development has been completed and final validation testing is underway.
  - New supports have been designed to support the probes in the newly identified locations for the Mid-western fuel host site. Quotes have been received for electrical work needed to accommodate the new installation.
  - Material samples for the probes have been machined and final assembly of probes for the second and third sites is underway.
- Issues with flux cored welding of SAVE12 were evaluated and development is still underway. Inclusions and ductility issues were the primary concerns.
- Coupons welded with higher heat input in Inco 740 contained fewer defects than lower heat input welds.
- Hot wire gas tungsten arc welding (GTAW-HW) showed promise for Inco 740 and more testing is planned.
- No recrystallization was detected in the Super 304H at any strain level after heating samples at 1300 and 1400^{o}F for up to 100 hours and the onset of recrystallization was identified only at the highest strain level after 1000 hours at 1500^{o}F.
- The onset of recrystallization was detected in highly strained CCA 617 samples that had been heated at 1500^{o}F for 10 and 100 hours and holding for 1000 hours increased the degree of recrystallization but did not decrease the onset strain level.
- Performed a 1400^{o}F/150 hour thermal exposure on the strained HR6W material.
- Alloy 230 tube samples, 2” OD by 8” long, that were machined to a 0.200” wall thickness were butt welded to 6’ long carbon steel tubes (for positioning and handling) in preparation for swaging trials.
- A study has been completed to assess the cycling capability and margins against shakedown and ratcheting for a typical segment from a superheater header subject to normal cold startup and rapid cooling on shutdown.

E. Plans for the Next Quarter

It is anticipated that the following work will be completed during the next quarter:

- Low cycle fatigue testing on the Haynes 230 will be started next quarter.

- Three Inconel 740 tube bends have been prepared for pressurized creep testing.

- Descaled weight loss and SEM/EDS evaluation of the steamside oxidation specimens removed following the third exposure at 800^{o}C will be completed. Specimens will be prepared and the first exposure at 900^{o}C will be started.

- The air cooled fireside corrosion probes will have mechanical and electrical modifications at all host sites completed and the probes will be installed and exposures started.

F. Issues

- Based on Sumitomo data in the LMP plot below, it appears that there is a large heat-to-heat variation in creep strength for different HR6W heats..

- Inconel 740 cross weld coupons demonstrated less creep rupture live using either 740 or 263 filler than base metal tests.

- Changes in fuel at our original fireside corrosion Eastern coal host site have necessitated locating a new host site. Discussions were held with a new plant in Ohio to replace the original third host site.

- Section “A” of the steam cooled fireside corrosion probes had difficulty making temperature.

- A special heat of Inco 740 designed to reduce microfissuring during welding was unsuccessful.

- SMAW welding of Super 304H was deemed not suitable for production welding.

- The use of matching filler metal for welding thick section CCA 617 plates does not appear practical.

2.0 Taskwise Status

Task 1
Conceptual Design and Economic Analysis
(Task lead EPRI)

The objective of Task 1 is to specify the temperature/pressure distribution for 760°C/35 MPa (1400°F/5000 psi) steam inlet conditions so that the data needs and the range of test parameters can be identified and the economics of material selection established.

Task 1A: Alstom Approach (Alstom Power Co.)

Objectives:

The primary objectives of this subtask are:

- Develop a conceptual boiler design for a high efficiency ultra supercritical cycle designed for 1400^{o}F steam temperature.
- Identify tubing and piping materials needed for high temperature surface construction.
- Estimate gas and steam temperature profiles so that appropriate mechanical, corrosion and manufacturing tests of materials could be designed and conducted to prove suitability of the selected alloys.

Progress for the Task

A final report has been completed and distributed.

Task 1B: Babcock Approach

Objective:

The objectives of this subtask are the same as in Subtask 1A.

Progress for the Quarter:

No work was performed on this task this quarter.

Concerns:

Progress for the Next Quarter:

A final report has been completed and distributed.

Task 1C: Economic Analysis

Objective:

The objective of this task is to determine relative economics of the USC plant.

Progress for the Task:

A final report has been completed and distributed.

Concerns:

None

Task 2
Mechanical Properties of Advanced Alloys
(ORNL)

The objective of Task 2 is to produce the mechanical properties database needed to design a boiler to operate at the steam conditions within the scope of the project.

Task 2A: Assessment of the Alloy Performance Requirements

Objectives:

The primary objectives of this subtask are:

- Focus on performance needed for boiler service in the temperature range of 650°C (1200°F) to 871°C (1600°F)
- Produce reports that justify the materials selected for the pressure retention components of the USC boiler

Progress for the Task:

ORNL attended the European Creep Collaborative Committee's (ECCC) 2005 Conference on Creep and Fracture in High-Temperature Components in London, UK (Sept. 2005). A number of issues dealing with USC boiler material technology were presented and ORNL will brief the consortium on the main issues during the next steering committee meeting.

Task 2B: Detailed Test Plan

Objectives:

The detailed mechanical properties test plan is intended to provide guidance on the scope of the mechanical testing for each material to support the resolution of issues related to the tasks undertaken in the project. Categories include: mechanical characterization; data production for the development of code cases; effects of fabrication variables; weldment performance; fatigue and thermal-fatigue behavior; and the like. The six alloys, chemical compositions in Table 1 below, of most interest to the project are: SAVE12, Super 304H, HR6W, Haynes 230, CCA617, and INCONEL 740. Specific heat chemistries are available on the website.

Progress:

The characterization testing plans have been completed for the creep-rupture testing of the five tubing alloys (Super 304H, HR6W, alloy 230, CCA617, and INCONEL 740). A test plan for the creep-rupture testing of Inconel 740 plate and SAVE12 pipe have also been produced. Progress and/or problems associated with the welding (Task 5) and fabrication (Task 6) tasks will define relevant testing. Thus, to some measure the test plan continues to evolve. Weldment test plans for HR6W, Super 304H, CCA617, and Super304H to CCA617 tubes have been produced. A test plan to evaluate 740 and 263 weld filler metals on Inconel 740 has been designed and testing has been completed. Thick section weldments plans are being produced as welded material becomes available. Test matrices for verifying and determining the LCF and creep-fatigue behavior of CCA617 and Inconel 740 have been designed and testing initiated. Discussions with Task 8 members have helped define the structural tests needed by the boiler manufactures to evaluate their respective component models. Notched bar test plans for Inconel 740 have been produced to evaluate the material's notch sensitivity and multi-axial creep behavior. Test plans in progress can be viewed on the website.

TABLE 1. Compositions of USC Steam Boiler Consortium Materials

					Nominal Compositions in Wt%										
Alloy	Fe	Cr	Ni	Mn	Mo	Ti	Nb	W	V	C	B	Si	N	Cu	Other
SAVE 12*	bal	11.0		0.2				3.00	0.20	0.10		0.3	0.04		3.0Co 0.07Ta 0.04Nd
Super 304H*	bal	18.0	9.0	0.8			0.40			0.10		0.2	0.10	3.00	
HR6W*	bal	23.0	43.0	1.2		0.08	0.18	6.00		0.080	0.003	0.4			
Haynes 230*	3.0	22.0	bal	0.5	2.0			14.00		0.10	0.02	0.4			5.0Co 0.3Al 0.02La
CCA617	0.6	21.7	bal	0.03	8.6	0.40				0.05	0.002	0.1	0.01	0.01	11.25Co 1.25Al
INCONEL 740	2	24.0	bal	0.3	0.5	2.0	2.0			0.07	0.002	0.5			19.8Co 0.8Al 0.015Zr

*Compositions are nominal and will be replaced by measured compositions in the future

Concerns:

None.

Task 2C: Long Term Creep Strength

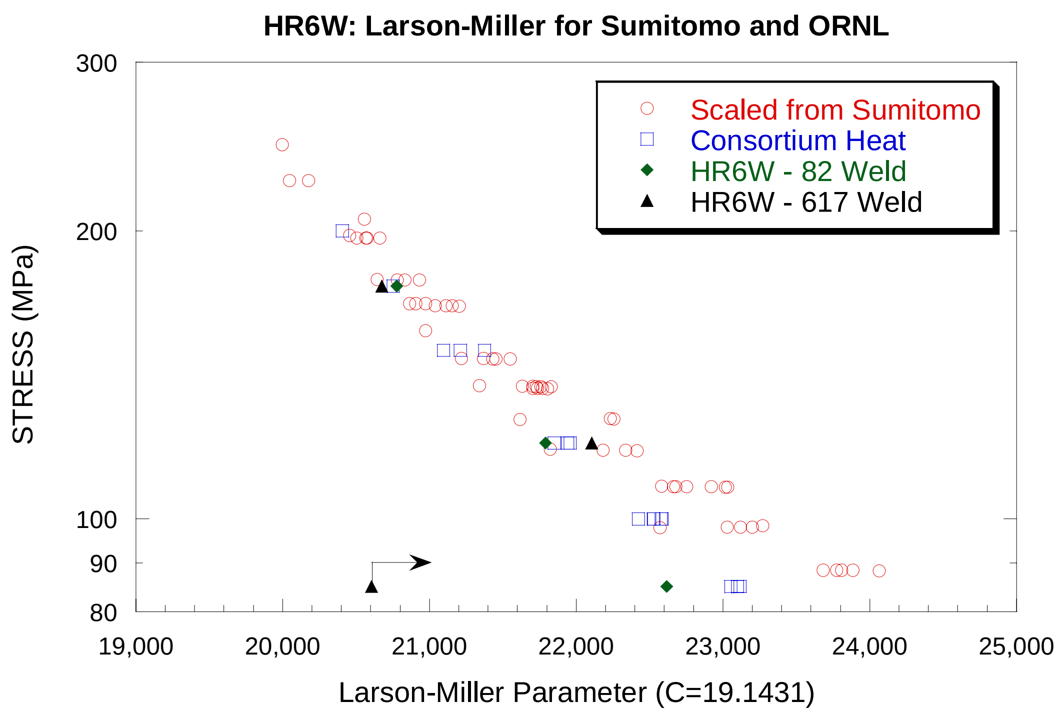
Objectives:

The primary objectives of this subtask are:

- Identify the general characteristics of the creep behavior and damage accumulation in the candidate alloys
- Verify the creep-strength of code-approved alloys
- Assess the creep-strength non code-approved alloys; and provide creep/creep-rupture data for a code case if deemed appropriate by consortium members
- Provide accurate creep data (i.e. creep-curves) for boiler design on the candidate materials

Progress:

The status and data for tubing alloys currently being tested is provided on the consortium website. Testing of the SAVE12 base metal began this month. The test matrix for the HR6W tubing was completed this month. The results confirm earlier predictions based off short-term data which indicated that the HR6W did not have a creep strength advantage compared to current austenitic boiler tubing. Based on Sumitomo data in the LMP plot below, it appears that there is a large heat-to-heat variation in creep strength for different HR6W heats and that the consortium heat is at the lowest end of the scatterband. Sumitomo has contacted ORNL to provide material from a new 'high creep strength' heat of HR6W. ORNL has asked for the mechanical properties data to evaluate the strength of the alloy before agreeing to more testing. The CCA617 alloy is exceeding expectations in the lower temperature regime (650°C to 700°C), based on performance equivalent to alloy 617. Test times have now exceeded 20,000 hours for some CCA617 tests. Microstructural studies suggest this strength difference is due to the precipitation of gamma prime at 700 to 800ºC. Grain size control and boron content may also be factors in the strength of CCA617. Larson-Miller-Parameter extrapolation shows the creep strength benefit may extend to 730°C for CCA617 vs. std. 617. All of the planned Super 304H tests continue. Testing is also progressing on the INCONEL 740 tubing and plate. 100 and 1000 hours rupture lives appear close to predictions based off previous work at ORNL and data from Special Metals but longer term tests are slightly shorter than predicted. The longest test times have reached approximately 8,000 hours and lower stress tests have been added to the matrix with expected rupture lives of 10,000 to 20,000 hours.



Task 2D: Microstructural Analysis

Objective:

The primary objectives of this subtask are:

- Identify the microstructural changes that lead to significant changes in the strengthening, weakening, and internal damage characteristics of each material.
- Explore how these changes relate to the exposure conditions of the testing.

Progress:

The University of Cincinnati, subcontract with ORNL to provide electron microscopy studies on aged and creep tested material, provided SEM (BSE and EDS) analysis of the creep tested 740 plate welded with 263 and 740 filler metal this quarter. Some general observations were:

For the 740 filler metal

1. Precipitates in weldment appear to M23C6 and MC type carbides based on EDS analysis.
2. No eta phase was observed in weldment.
3. Creep failure was by wedge cracking which appeared to be associated with the regions between welding passes.
4. Gamma prime and eta phase precipitate structure (observed after etching in the SEM) was different for the base metal and weldment.

For the 263 filler metal

1. Interdendritic regions were enriched in Nb, and no other large compositional variations could be found in the weldment.
2. Creep failure was by cavitation and was not obviously associated with any precipitate or dendritic structure.

Task 2E: Assessment of Creep-Fatigue Properties

Objective:

The primary objectives of this subtask are:

- Verify the low cycle fatigue, creep-fatigue, and thermal mechanical fatigue properties of the thick section alloys.

- Develop a database that will lead to practical, yet conservative methods for new materials.
- Address the issue of creep-fatigue in the boiler materials.

Progress:

LCF testing on Inconel 740 (Heat #BLT2819 - plate) was started this quarter. A summary of the results, to date, is shown below. More tests will be required to establish the baseline behavior of the 740 base metal and creep-fatigue tests are planned as well. The results have not been updated on the website. ORNL is determining the best way to put the large LCF datafiles on the website. LCF testing on the Haynes 230 (taken from 3" thick plate) will be started next quarter to compare the properties relative to the Haynes 230 database and the CCA617.

Specimen ID	Test Number	Material Condition	Temp. C	Waveform	R-ratio	Total Strain Range (%)	Peak Hold Time (sec)	Strain Rate (/sec)	Cycles to Failure	Break Location
740-F02	30638	Age 16hrs 800C	750	Triangular	0	0.7	none	0.001	1737	Gauge - Outside Ext.
740-F03	30652	Age 16hrs 800C	750	Triangular	0	0.4	none	0.001	13228	Gauge - Outside Ext.
740-F04	30686	Age 16hrs 800C	750	Triangular	0	0.3	none	0.001	95759	Gauge - Outside Ext.
740-F05	30685	Age 16hrs 800C	750	Triangular	0	1	none	0.001	35	Gauge - Inside Ext.
740-F06		Age 16hrs 800C	750	Triangular	0	0.45	none	0.001		
740-F07	30618	as-received	750	Sine	0	0.7	none	(0.0714Hz)	1137	Gauge - Inside Ext.
740-F08	30633	as-received	750	Triangular	0	0.7	none	0.001	776	Gauge - Inside Ext.

Task 2F: Modeling of Weld Joints

Objectives:

The primary objectives of this subtask are:

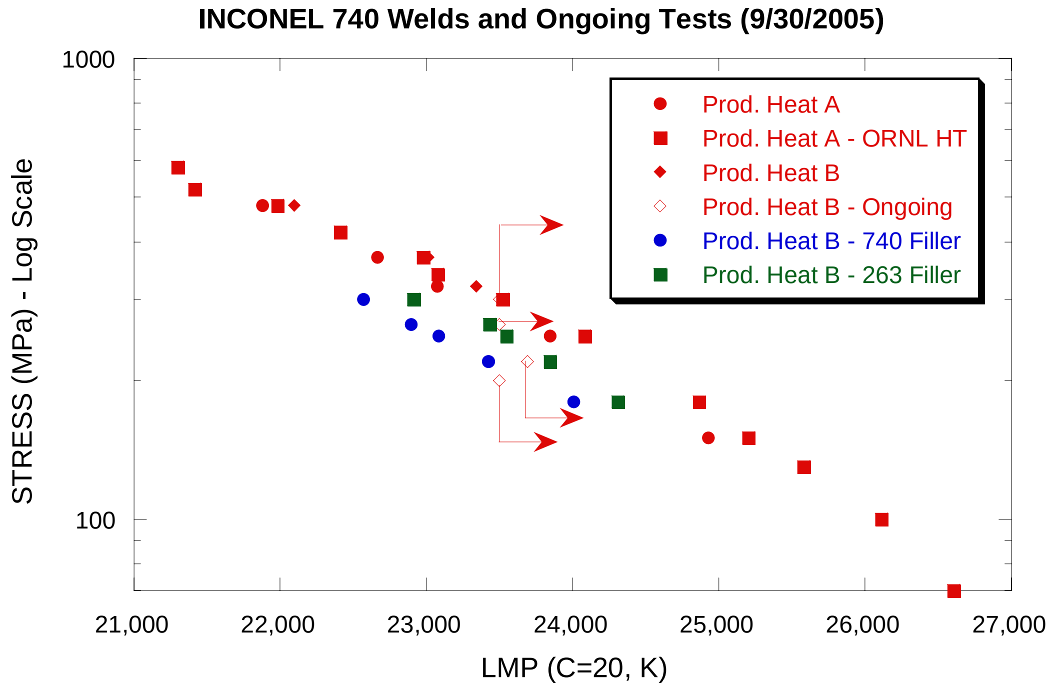
- Produce the experimental data needed to model dissimilar metal and thick-section weld joints.

Progress:

Creep-rupture testing continues on Haynes ® 230 plate weldments and HR6W butt-welded tubes. Tabular results are available on the website. Short-term cross-weld creep-rupture testing has been completed on a 5/8" thick Inconel 740 plate welded with both 740 and 263 filler metal. The purpose of these tests was to evaluate the differences between the weld strength of the two filler metals. Wrought Inconel 740 has superior creep strength compared to wrought 263 but data is not available on the weld metal strength for these alloys. 263 is the preferred filler from a weldability standpoint for joining 740. Based on the results shown in the table and plot below (max rupture time of 2,000 hours), the 263 weld metal creep-rupture strength is greater than that of the 740. All ruptures were in the weld metal irrespective of weld metal type. Microstructure studies are ongoing to understand the differences in creep strength. Testing is ongoing for the large cross-weld specimens from the SAW and SMAW CCA617 2” thick plate weldments. The specimen dimensions being tested are: 16” overall specimen length with a gauge section 5.5” long x .32” thick x .75” wide. Testing of butt-welded tubes of CCA617, Super304H, and CCA617 to Super304H started this quarter. No results are available as these tests have just begun. The 3” thick Haynes 230 weldment has been received, but machining of specimens has not begun due to FY06 funding considerations.

Inconel 740 Plate (Heat #BLT2819 -5/8") with 740 filler metal Cross-Weld Creep-Rupture Testing							
Spec #	**Test #**	**Stress (Mpa)**	**Temp. (°C)**	**BM Estimated Life**	**Date Started**	**Life (hrs)**	**Rupture Location**
740FM-W01	30595	**300**	**750**	1000	6/7/2005	115.4	weld
740FM-W02	30609	**180**	**800**	1000	6/13/2005	237	weld
740FM-W03	30630	**220**	**750**		7/6/2005	790	weld
740FM-W04	30631	**250**	**750**		7/6/2005	367.6	weld
740FM-W05	30648	**265**	**750**		7/28/2005	240.1	weld

Inconel 740 Plate (Heat #BLT2819 -5/8") with 740 filler metal Cross-Weld Creep-Rupture Testing							
Spec #	**Test #**	**Stress (Mpa)**	**Temp. (°C)**	**BM Estimated Life**	**Date Started**	**Life (hrs)**	**Rupture Location**
740FM-W01	30595	**300**	**750**	1000	6/7/2005	115.4	weld
740FM-W02	30609	**180**	**800**	1000	6/13/2005	237	weld
740FM-W03	30630	**220**	**750**		7/6/2005	790	weld
740FM-W04	30631	**250**	**750**		7/6/2005	367.6	weld
740FM-W05	30648	**265**	**750**		7/28/2005	240.1	weld



Task 2G: Study of Accelerated Test Methods

Objectives:

The primary objective of this task is:

- Provide a method to rapidly characterize changes in the strength of candidate materials.

Progress:

No new materials have been identified for relaxation testing. This task is complete until an evaluation of a new material is needed or Task 8 determines a critical data need.

Task 2H: Model Validation

Objectives:

The primary objective of this task is:

- Produce a database that can be used to confirm or validate design rules that are developed in Task 8.

Progress:

Pressurized creep testing of tube U-bends, to evaluate coldwork effects, was completed on the HR6W tube bend and two Haynes 230 bends. The Haynes 230 bends were stopped after testing for 8,000 hours without rupturing, but the HR6W was removed upon rupture after 7108.9 hours. All specimens were measured and some have been sectioned for metallography. Metallography will be performed on the Haynes 230 next quarter.

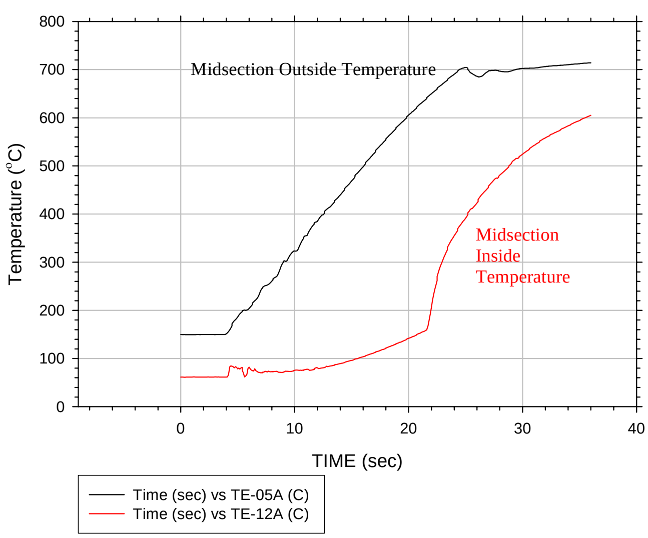
Three . Inconel 740 tube bends have been prepared for testing. Haynes 230 end caps were welded to the 740 tube bends using Nimonic 263 filler this quarter. Radiography is being performed and testing will begin next quarter.

Thermal shock testing on a CCA617 tube continued this quarter. Over 2000 thermal cycles have been complete with a 400°C upshock temperature gradient through the wall of the tube (see image below). A table of results is shown below.

Thermal Shock Test: CCA617

EVENT	MAX TEMP (C)	MIN TEMP (C)	UPSHOCK RATE (sec)	HOLD TIME (sec)	COOL DOWN (sec)	NUMBER OF CYCLES	TOTAL NUMBER OF CYCLES
Test	750	150	20	60	1200	330	330
Test	750	150	40	360	1200	4	334
Test	750	150	40	120	1200	67	401
Test	750	150	20	120	1200	683	1084
Inspection	No evidence of cracking during visual inspection. Thermocouples were repaired						**1084**
Test	750	150	20	120	1200	1188	2272
Inspection	Die penetrate showed very small indications indicating initial stages of cracking						**2272**
Test	750	150	20	120	1200		

Typical cycle



Concerns:

Uncertainties in the budget for ORNL for FY2006 will limit the amount of new testing performed at ORNL next quarter. Until a budget resolution is reached, no new specimens will be machined for the program (this includes specimens from the 3” thick Haynes 230 plate for evaluating weldment properties, the SAVE12 weldments, additional LCF specimens needed to establish the baseline LCF behavior of Inconel 740, additional thermal shock specimens, etc.). Current testing activities will not be impacted but new testing will be delayed.

Plans for Next Quarter:

Creep-rupture testing of all materials will continue. Pressurized creep testing of Inconel 740 tube bends will start. LCF testing will continue for Inconel 740 and will be started for Haynes 230. Testing of weldments, including the thick section welds of the CCA617, will continue. Thermal shock testing of CCA617 will continue.

Task 3
Steamside Oxidation
(B&W)

Task 3A: Autoclave Testing

Background:

Steamside oxidation tests will be performed on commercially available and developmental materials at temperatures between 650°C and 900°C (1202°F - 1652°F).

Experimental:

During the past quarter, evaluation of the specimens removed following the second exposure at 800°C was completed. Also during the past quarter, the third exposure at 800°C was conducted and the evaluation of these specimens was begun.

<u>Weight Change</u>

- Alloys T23, P92 and SAVE12 experienced extremely high oxidation rates at 800°C. Austenitic materials S304H Tube, 347HFG Tube, SB 347HFG and 347HFG experienced significant oxide exfoliation. In general, the weight gain behavior of the remaining materials followed parabolic kinetics.

- The lowest mass change was exhibited by the Ni-based Alloy 214, which contains only 16% Cr, but also contains ~4.5% Al. Apart from those materials that exhibited exfoliation, the remaining materials exhibited mass changes within a factor of 3 from each other after 4,000 hours of exposure at 800°C. It is interesting to note that this range encompasses both the Ni-based alloys as well as the ferritic alloys MARB2 and VM12.

<u>Effect of Shot Blasting</u>

- The effect of ID shot blasting on the steamside oxidation of SUPER304H and 347HFG was evaluated from the results from materials Tube S304H, SB S304H, Tube 347HFG and SB 347HFG. The specimens from these materials were prepared such that one surface of the specimen was the original ID of the tubing, as shown in Figure 1.

- The composition of the tubing is listed in Table 1. Since the composition of the shot blasted and non-shot blasted SUPER304H tubes and the shot blasted and non-shot blasted 347HFG tubes are very similar, the only difference in the test results should be due the effect of the shot blasted ID surface. The results from these materials suggest that shot blasting is effective in reducing the exfoliation experienced by these materials. Since the shot blasted specimens were only exposed for 2,000 hours, information regarding the long-term beneficial effect of shot blasting could not be ascertained. The efficacy of this procedure in reducing the oxidation rate of these materials will be determined after the shot blasted specimens are descaled and weighed.

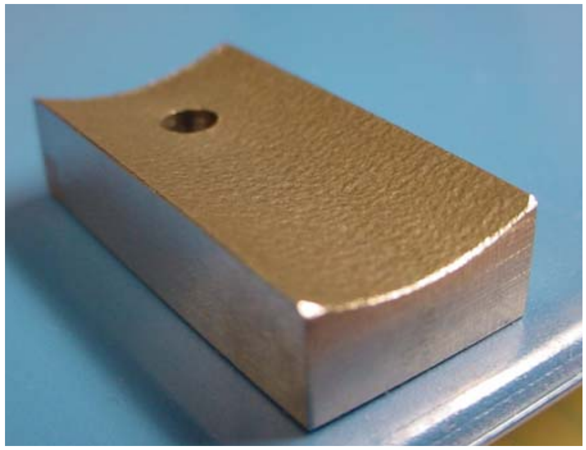


Figure 1. Test Specimen Used to Study the Effect of Shot Blasting

TABLE 1

Chemical Composition of Test Materials								
Material	**C**	**Si**	**Mn**	**Fe**	**Cr**	**Ni**	**Nb**	**Cu**
Tube 347HFG	0.082	0.39	1.59	Bal	18.41	11.59	0.92	---
SB 347HFG	0.09	0.44	1.51	Bal	18.6	11.65	0.9	---
Tube S304H	0.084	0.22	0.84	Bal	18.26	8.62	0.53	2.89
SB S304H	0.08	0.24	0.91	Bal	18.73	8.92	0.47	2.76

Descaled Weight Loss / k_p

Parabolic rate constants from B&W data and ORNL data were compared. The B&W results were calculated based on descaled weight loss, while the ORNL results were calculated from measured weight gain. In many cases there is good general agreement between the B&W and the ORNL data. It must be remembered that the ORNL tests were performed under somewhat different environmental conditions than the B&W tests:

- B&W uses OT water (pH 8-8.5; 100-300 ppb O_2), ORNL uses deaerated deionized water
- B&W tests at atmospheric pressure, ORNL tests at 250 psig.

Oxide Appearance/Morphology and Chemistry

As reported previously, T23 specimens experienced through-thickness oxidation after 1,000 hours in steam at 800°C. Oxide nodules formed on P92 and SAVE12 after 1,000 hours in 800°C steam, and continued to spread across the surface of these specimens throughout the remainder of the exposures, as shown in Figure 2.

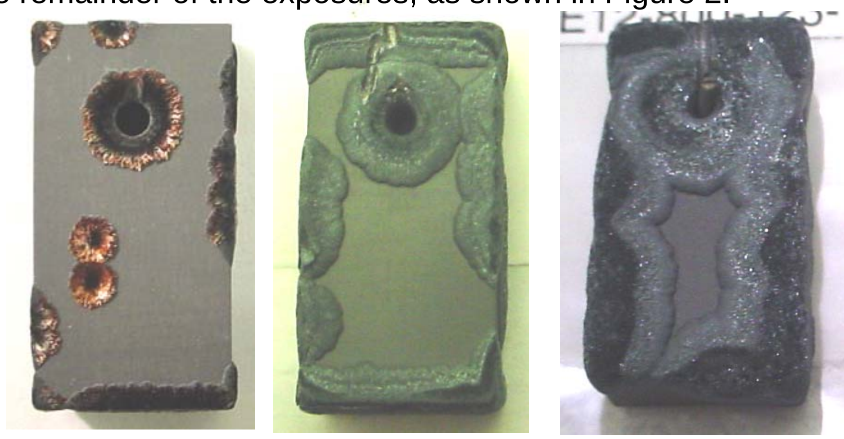


Figure 2. Growth of Oxide Nodules on SAVE12 in 800°C Steam (different specimens are shown)

Microscopic evaluation of MARB2 specimens after 1,000 and 2,000 hour exposures in steam at 800°C revealed that oxide nodules had begun to form on this material. After a 4,000 hour exposure, these nodules had become visible to the naked eye, as shown in Figure 3

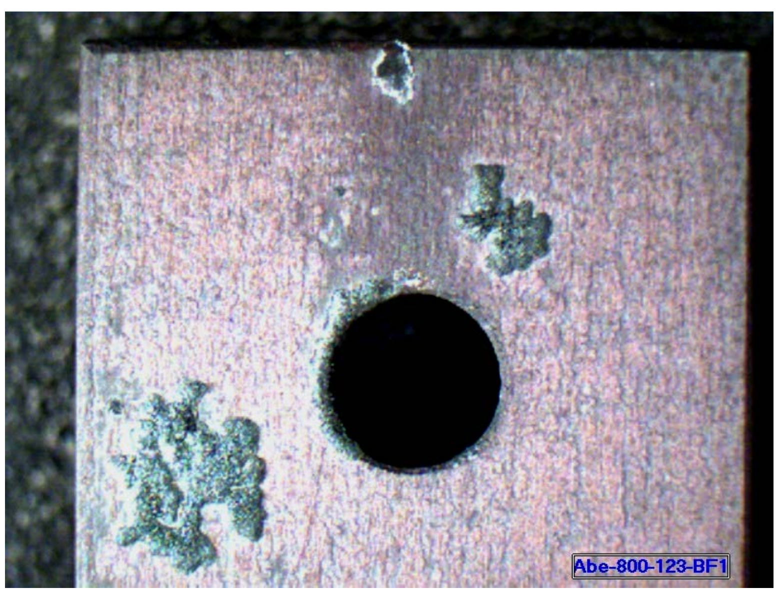


Figure 3. Oxide Nodules Formed on MARB2 (Abe) After 4,000 Hours of Exposure in 800°C Steam

The intergranular aluminum oxide penetrations observed in CCA617 and Alloy 230 after 1,000 hours of exposure did not grow during the second 1,000 hour exposure. The intergranular aluminum oxide penetrations observed in Alloy 740, however, were ~50% deeper after the second 1,000 hour exposure than after the first 1,000 hour exposure.

The microstructure of several of the test materials continued to evolve during the 800°C exposures due to accelerated kinetics at this elevated temperature.

Concerns:

None.

Activities Next Quarter:

Descaled weight loss and SEM/EDS evaluation of the specimens removed following the third exposure at 800°C will be completed. Specimens will be prepared and the first exposure at 900°C will be started.

Task 3B Coating Tests

Background:

Coated specimens for steamside oxidation testing will be prepared in conjunction with Task 7 and evaluated after testing.

Experimental:

- Weight. change results on coated specimens suggest that the CrS304H specimens are experiencing some degree of oxide exfoliation or general dissolution. The SiCrS304H specimens have experienced weight gains comparable to those exhibited by wrought high chromium nickel-rich materials. The weight gains experienced by the AlCrS304H specimens were higher than all materials except the wrought ferritic materials that formed oxide nodules.

- Descaling of chromized specimens yields results that are generally not as accurate as results generated on wrought materials; however, the results suggest that the SiCrS304H material has exhibited the best overall performance of the three coating formulations. The descaled weight loss of the SiCrS304H is only slightly more than that exhibited by materials such as VM12 and 310HCbN.

Concerns:

None.

Activities Next Quarter:

CrS304H, AlCrS304H and SiCrS304H specimens will be entered into test at 900°C.

Task 3C Assessment of Temperature

Background:

Based on the steamside oxidation test results, the practical temperature limits for the materials tested will be determined.

Experimental:

Activation energies from B&W and ORNL are being evaluated.

Concerns:

None.

Activities Next Quarter:

Activation energies will be re-calculated following the third 800^{o}C exposure.

Task 3D Review of Available Information & Reporting

Background:

Available steamside oxidation literature pertaining to materials and environmental conditions of interest will be reviewed. Project status updates will be prepared and status meetings will be attended as required.

Experimental:

Monthly status reports were prepared for July and August, 2005. A Steering Committee Meeting was attended in Cleveland, OH in August.

Concerns:

None.

Activities Next Quarter:

Monthly status reports will be written for October and November. A Quarterly Report will be written for July – September, 2005.

Task 3E Conduct Experimental Exposures

Background:

The steam oxidation behavior of model Fe-Cr alloys will be evaluated.

Experimental:

B&W is remaining cognizant of the ORNL tests on these model alloys.

Concerns:

None.

Activities Next Quarter:

BWRC will maintain cognizance of ORNL results.

Task 3F Characterization

Background:

Samples of the model Fe-Cr alloys fabricated in Task 3E will be characterized before and after steamside oxidation testing using metallographic and electron optic techniques.

Experimental:

None.

Concerns

None.

Activities Next Quarter:

None.

Task 3G Data Analysis and Coordination

Background:

The steamside oxidation results will be evaluated to determine the effects of material properties and environmental factors on oxidation behavior.

Experimental:

No progress will be possible until the steamside oxidation tests have been completed (GFY2006).

Concerns:

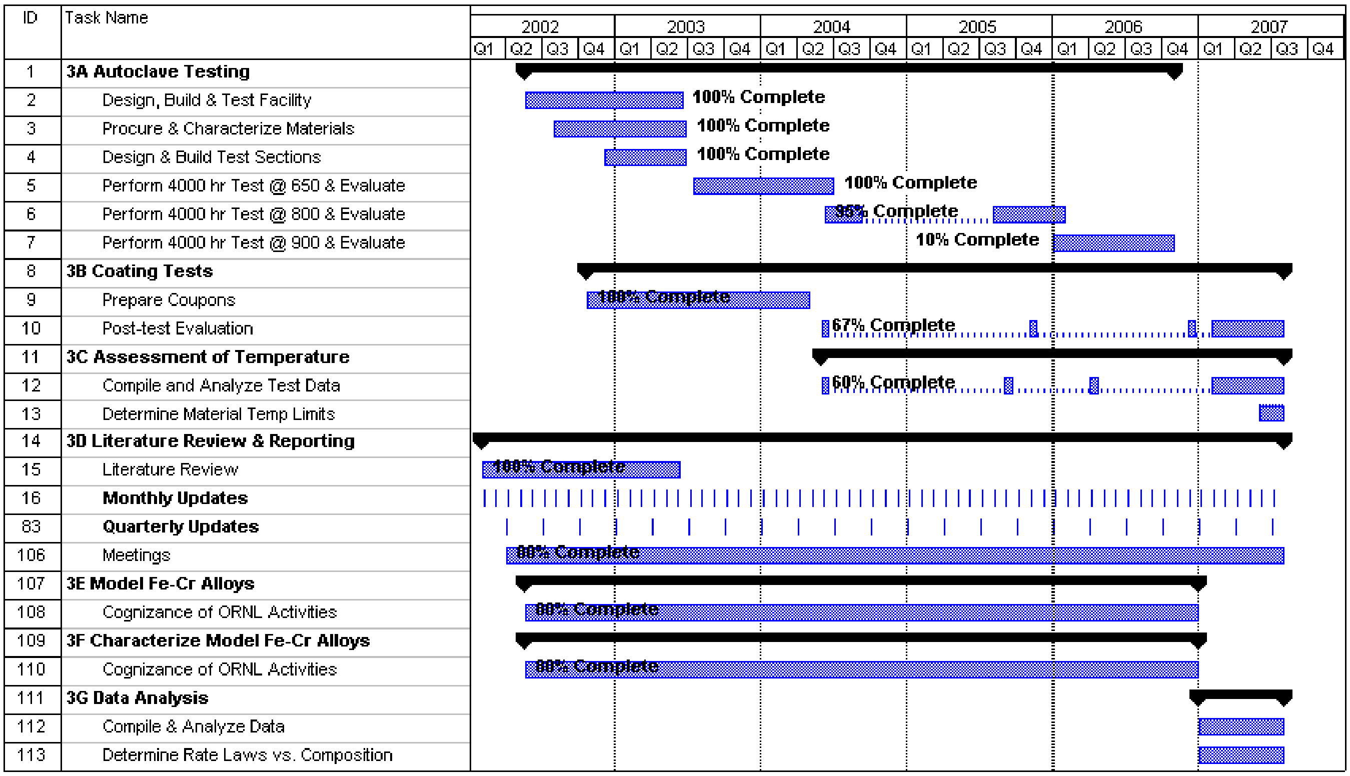
None.

Activities Next Quarter:

None.

Milestone Chart:

Dates are listed in GFY.



Task 3
Steamside Oxidation
(ORNL)

Activities This Quarter

Oxidation Kinetics

Oxidation exposures to 4kh at 650°C in 17 bar steam were completed for all alloys except MARB-1 and -2, and 347HFG. The mass-based kinetic data have been reported in the B&W quarterly report. Of particular note are the significantly lower oxidation rates measured at 650°C for the MARB alloys, compared to the other 9-12Cr steels, see Fig. 1. By inspection of the

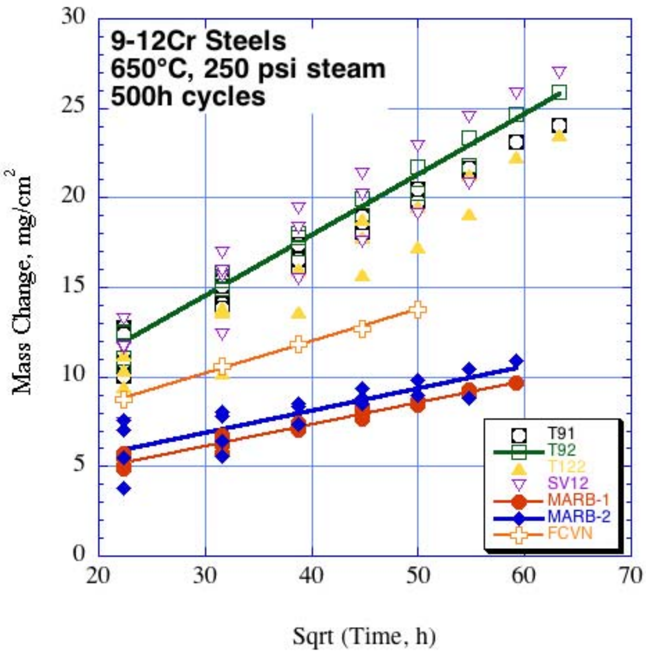


Figure 1. Parabolic Plots for Kinetics of the 9-12Cr Steels Oxidized in 17 bar Steam at 650°C

chemical compositions of this alloy class (Table 1), it appears that the oxidation behavior of the MARB alloys has been controlled through the incorporation of a relatively high level of Si,.

Table I. Compositions of Ferritic Steels Tested

Alloy	Composition, weight percent														
	Ni	Co	Cr	V	Mo	W	Mn	Si	Al	C[a]	N[a]	S[a]	P[a]	B[a]	Cu	Other
T91	0.13	0.01	8.3	0.26	0.9	0.01	0.34	0.13	—	790	537	10	70	30	0.03	0.07Nb
T92	0.13	0.01	9.2	0.24	0.5	1.8	0.45	0.16	0.01	1100	583	50	100	40	0.05	0.05Nb
MARB-1[b]	—	3.3	9.2	0.2	—	2.5	0.5	0.74	0.001	820	10	60	10	100	—	0.05Nb
MARB-2[b]	—	3.0	9.2	0.2	—	2.5	0.5	0.73	0.002	820	20	50	10	190	—	0.05Nb
SAVE12	0.01	2.68	9.3	0.3	—	2.9	0.54	0.28	—	1200	—	10	140	40	—	0.05Nb
T122	0.35	0.02	10.6	0.22	0.36	1.9	0.67	0.12	—	1100	746	<10	130	20	0.83	0.04Nb
FCVN	0.55	3.45	11.1	0.59	0.53	1.1	2.09	0.06	0.01	310	1558	20	90	—	0.02	0.02Nb;0.01Ti

a: in ppmw
b: B&W analysis

together with the optimum level of S (see Fig. 2), which exerts a large effect that is apparently independent of alloy Si content. In fact, it seems probable that the MARB alloys incorporate close to the optimum alloying adjustments for maximizing oxidation resistance that are consistent with attaining creep strength goals.

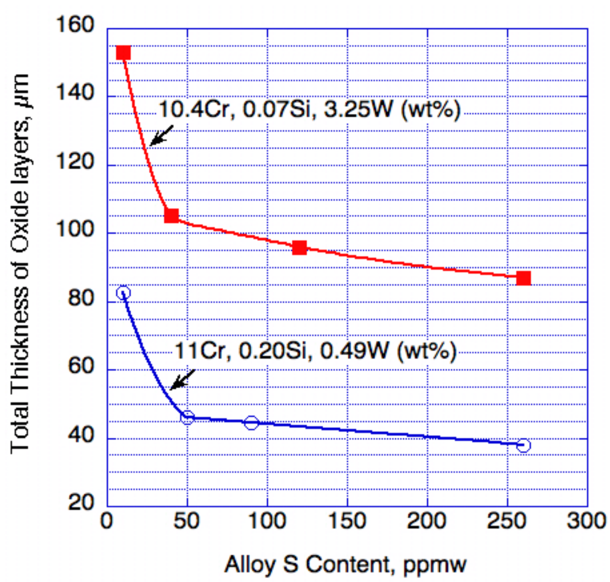


Figure 2. Effect of S (and Si) Content of 10Cr steels on Total Oxide Thicknesses Formed After 1000h at 650°C in 1 bar Steam (after Murata et al., 2001).

Alloy FCVN (an ABB/Alstom developmental alloy), which also has shown significantly slower oxidation kinetics in the current test series (especially at T > 650°C), achieves improved oxidation resistance via a different route than that used by the MARB alloys (Table I). Principally, the improvements in FCVN apparently result from the increased Cr level; the Si and S levels are relatively low, whereas the levels of Co, Mn, and V are higher than is typical for this class of alloys. Of these elements, only Mn might be considered beneficial for oxidation resistance, due to its ability for rapidly form mixed

Mn-Cr spinel oxides, which would be expected to promote the early formation of Cr-rich oxide layers at the alloy-oxide interface.

The extent of the improvement in oxidation behavior for the MARB alloys is illustrated in Table II, in terms estimated total oxide thicknesses expected after 40kh (made from the mass gain

Table II. Oxide Thicknesses Calculated From Mass Gain Kinetics

Alloy	**650°C**		**After 40kh at 650°C**	
	k_p (x 10^{-12}) $g^2cm^{-4}s^{-1}$	R^2	mass gain (g/cm^2)	oxide thickness[a] (μm)
T91	27	0.97	0.06	546
T92	32	0.98	0.07	598
MARB-1	4.0	0.96	0.02	213
MARB-2	4.1	0.66	0.02	215
SAVE12	39	0.93	0.07	658
T122	33	0.89	0.07	608
FCVN	8.7	1.00	0.04	312

[a]assuming oxide is all magnetite ($\rho_{ox\text{-}eff}$ = 4.1 gcm^{-3})

kinetics and assuming that the scales are essentially magnetite, with an effective density of 4.1 g/cm^3). These calculated values of scale thicknesses may, in fact, be too large if the scales contain significant amounts of Cr-rich basal layers (metallographic examination not yet conducted). On the simplifying assumption that tendency for scale exfoliation is directly linked the scale thickness (stored strain energy), the potential advantage of the MARB alloys is obvious. The actual scale thicknesses formed of the MARB alloys in the 4kh tests will be measured to provide correlation of these mass-based projections.

Following careful re-examination of the metallographic data, the oxidation kinetics for earlier runs at 700 and 800°C, based on measurements of total metal thickness loss (uniform loss plus internal penetration), are summarized in Table III. Note that, for all alloys tested, the oxidation kinetics over the 4kh exposures were well described by a parabolic rate law. The Table reports the parabolic rate constants (in $\mu m/h^{0.5}$), and lists an extrapolation of the metal loss in one year.

Table III. Steady-State Oxidation Rates From Metallographic Thickness Measurements (4kh in 500-h increments, in 17 bar steam)

Alloy	Total Metal Loss, µm/h$^{0.5}$ (mil in 1 yr)			
	700°C		800°C	
	Av	Max	Av	Max
T91	2.7 (10)	2.8 (10)	—	—
T92	2.6 (10)	2.8 (10)	—	—
T122	1.6 (5.8)	2.0 (7.3)	—	—
FCVN (11Cr)	0.69 (2.5)	0.8 (2.9)	6.2 (23)	7.0 (26)
310HCbN	0.35 (1.3)	0.38 (1.4)	0.49 (1.8)	0.83 (3.1)
SAVE25	0.24 (0.9)	0.32 (1.2)	0.84 (3.1)	0.93 (3.4)
Super304H	—	—	2.1 (7.8)	2.2 (8.2)
NF709	0.25 (0.9)	0.31 (1.1)	0.52 (1.9)	0.71 (2.6)
HR120	0.35 (1.3)	0.44 (1.6)	0.55 (2.0)	0.64 (2.4)
Haynes 214	—	—	0.19 (0.7)	0.27 (1.0)
HR6W	—	—	0.38 (1.4)	0.57 (2.1)
Haynes 230	—	—	0.59 (2.2)	0.67 (2.5)
CCA617	—	—	0.74 (2.7)	0.93 (3.4)
IN740	0.24 (0.9)	0.30 (1.1)	0.71 (2.6)	0.87 (3.2)
PM-Cr	0.12 (0.4)	0.18 (0.7)	—	—

Chromium Volatility in Steam

Figure 3 compares the vapor pressure of the most volatile Cr species, $CrO_2(OH)_2$, as a function of temperature and total pressure, from calculations using the latest thermodynamic data for this system. The results of further calculations of the mass transport of Cr (metal) from the surfaces of laboratory-sized alloy coupons to the steam are summarized in Table IV (note that the values of J_{Cr} are for laboratory-sized alloy coupons, and for the low steam low rates in the test rigs). These data suggest that the vapor pressure of $CrO_2(OH)_2$ in steam at the temperatures and pressures used in the laboratory tests would be much lower than at boiler operating conditions, and that the loss of Cr also would be small, but could become significant at the higher temperatures at 240-340 bar. Note also from Fig. 3 that a significantly higher vapor pressure of $CrO_2(OH)_2$ is generated in an air-10% water vapor mixture; over the temperature range of interest, the vapor pressure in the air-water vapor mixture is estimated to be similar to that in steam at 240-340 bar.

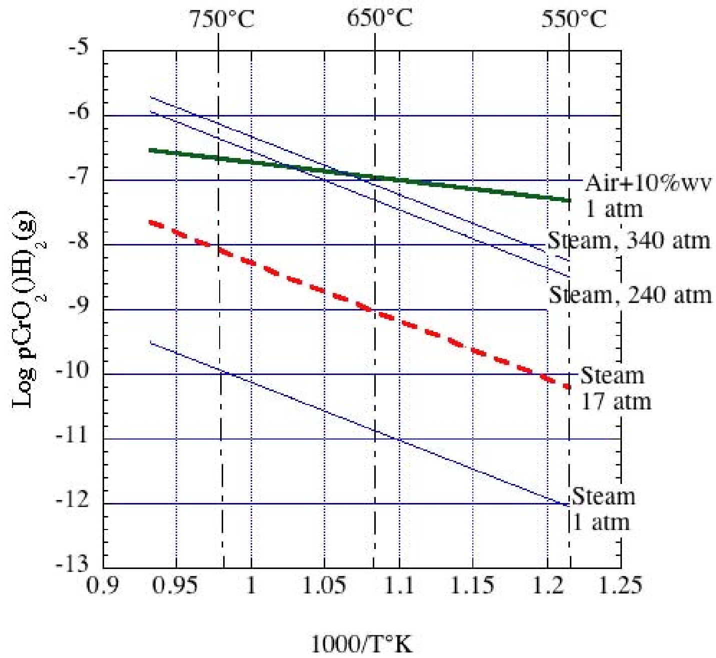


Figure 3. Temperature- and Total Pressure-Dependence of the Vapor Pressure of $CrO_2(OH)_2$

Table IV. Calculated Cr Loss by Volatilization in Steam

Steam at 241bar				
Temperature		$pCrO_2(OH)_2$	J_{Cr}* (Cr metal)	
°C	°F	atm	g/cm^2s	mg/cm^2yr
650	1202	5.0×10^{-8}	1.4×10^{-12}	0.04
700	1292	1.6×10^{-7}	4.2×10^{-12}	0.13
800	1382	1.2×10^{-6}	3.0×10^{-11}	0.95

*D.J. Young and and B.A. Pint, "Chromium volatilization rates from Cr_2O_3 scales into flowing gases containing water vapor," to be submitted for publication, 2005.

The formation of $CrO_2(OH)_2$ via::

$$½Cr_2O_3(s) + ¾\ O_2(g) + H_2O(g) = CrO_2(OH)_2(g) \qquad (1)$$

is dependent on the presence of oxygen which, in pure steam, comes from the equilibrium dissociation of steam via:

$$H_2O(g) = H_2(g) + 1/2O_2(g) \qquad (2)$$

This raises the question of the effect of additions of oxygen to steam on the effective oxygen partial pressure, hence $CrO_2(OH)_2$ partial pressure. The relationship between fraction of water vapor dissociated (at equilibrium) on the partial pressure of oxygen (from eqtn. 2) and the fraction of oxygen added to the steam was calculated, and the result is summarized in Fig. 4. This appears

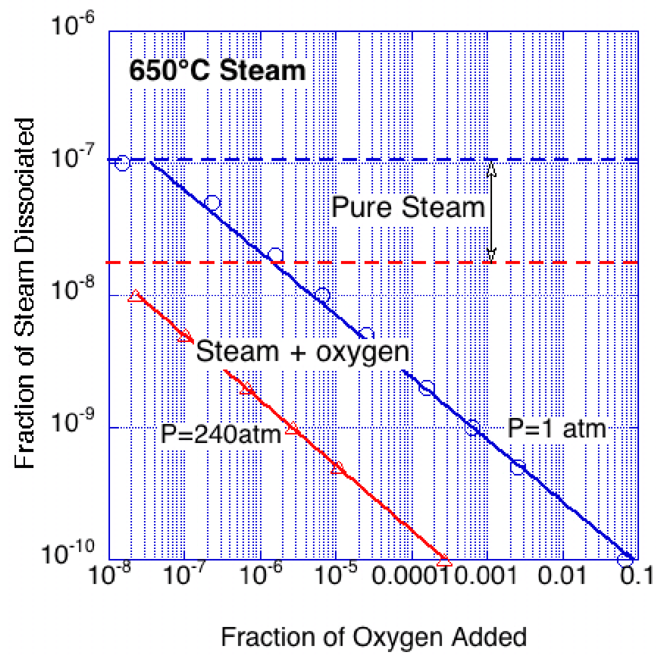


Figure 4. Relationship Between Fraction of Steam Dissociated and Fraction of Oxygen Added to Steam (for conditions of 650°C and 1 and 243 bar).

to indicate that, as the fraction of added oxygen is increased, the amount of oxygen from the dissociation of steam decreases, i.e., the case considered in the calculation was simply that of a buffered system, which acts to maintain the oxygen potential set by the equilibrium in eqtn. 2. Overall, if equilibrium dissociation conditions exist in the steam tubes (which contain large surface areas of nominally catalytic oxide), differences in the levels of oxygen added with the water would not be expected to change the effective oxygen partial pressure of the steam, hence should have no effect on the extent of Cr volatilization. If in practice there is found to be an obvious effect of the oxygen level in the steam (starting water), then the implicit assumption of the calculation—that equilibrium is reached—is wrong.

Concerns:

As a means of estimating any possible contribution from volatility losses in the measured kinetics, comparison was made of the measured mass gain data with those corresponding to the measured scale thicknesses for the austenitic steels and the Ni-base alloys tested (assuming the scales were all chromia). These comparisons indicated that the mass gains corresponding to the oxide thicknesses were consistently and significantly higher than the measured, overall mass gains, even for PM-Cr. This result suggests that, either all alloys lost scale due to spallation (this does not seem to be the case from low-power topographical examination and metallurgical cross sections), or that there was significant formation and loss of a volatile species. However, the calculations discussed above, based on the assumption of the formation of volatile chromium oxy-hydroxide $CrO_2(OH)_2$, suggested that associated mass losses should have been much lower than those measured (even for PM-Cr).

Reasons for this discrepancy are not obvious, but could involve: (1) unaccounted scale loss due to spallation; (2) faster volatilization than calculated; or (3) the formation of other volatile species. Plans are in hand to examine these possibilities.

The high-pressure team exposures at CCTechnologies have been delayed by a persistent leak in the autoclave. Exhaustive checking of the system revealed a pinhole in a weld in the reactor body, so that the system has been disassembled for the weld to be remade.

Activities Next Quarter:

The testing in steam will continue to provide 4kh data for the remaining alloys, and to test approaches for improving the mass balance from these tests. Metallographic examination of specimens removed from test at 650°C will continue, as funding permits. Examination of possible scenarios for the discrepancies between measured and expected mass gains will continue.

Task 4
Fireside Corrosion
(Foster Wheeler)

The objective of the task is to evaluate the relative resistance of various advanced alloys for waterwall and reheater/superheater construction to fireside corrosion over the full temperature range expected for the USC plant. The corrosive environment promoted by three different coals, representative of an eastern coal, a midwestern coal, and a western coal, will be evaluated.

Task 4A: Laboratory Testing

Objective:

The objective of this sub-task is to perform laboratory corrosion tests on the candidate alloys. This will be accomplished by exposing metal coupons to various deposits and flue gases representative of three coals (e.g., eastern, midwestern, and western) at the range of temperatures expected for the USC plant.

Experimental Progress:

- During the quarter, the results of the metallographic examination of the superheater/reheater samples for carburization were incorporated into the wastage data. The graphical results (metal loss plus subsurface penetration due to oxidation/sulfidation/carburization) for the superheater/reheater samples were presented in Figures 1 through 5 in the July 2005 Monthly. Photographs were taken comparing the post-test macroscopic appearance of the laboratory specimens of each alloy to the various test conditions – examples for alloys Super 304H and In-740 are shown in Figures 1 and 2, respectively. Photographs were also taken comparing the macroscopic appearance of various alloy groups exposed to all three-test conditions. Figures 3 through 6, herein, illustrate the macroscopic appearance of various wrought and weld-overlay superheater/reheater specimens exposed to Eastern conditions. Graphs of wastage versus temperature were made for various wrought superheater/reheater alloys for all three-test conditions. Graphs were also made with the wastage results of the weld overlays and 50/50 laser clad superimposed in order to compare the performance of weld overlays against the wrought alloys. The graph comparing the wastage results of five wrought alloys (740, 230, 617,HR6W, and S304H) to the 52 and 72 weld overlays and the 50/50 laser clad tested under Eastern conditions is shown in Figure 7. Graphs showing the effect of chromium on wastage were also made for all of the tests temperatures – the graph for the 1400F test is displayed in Figure 8.

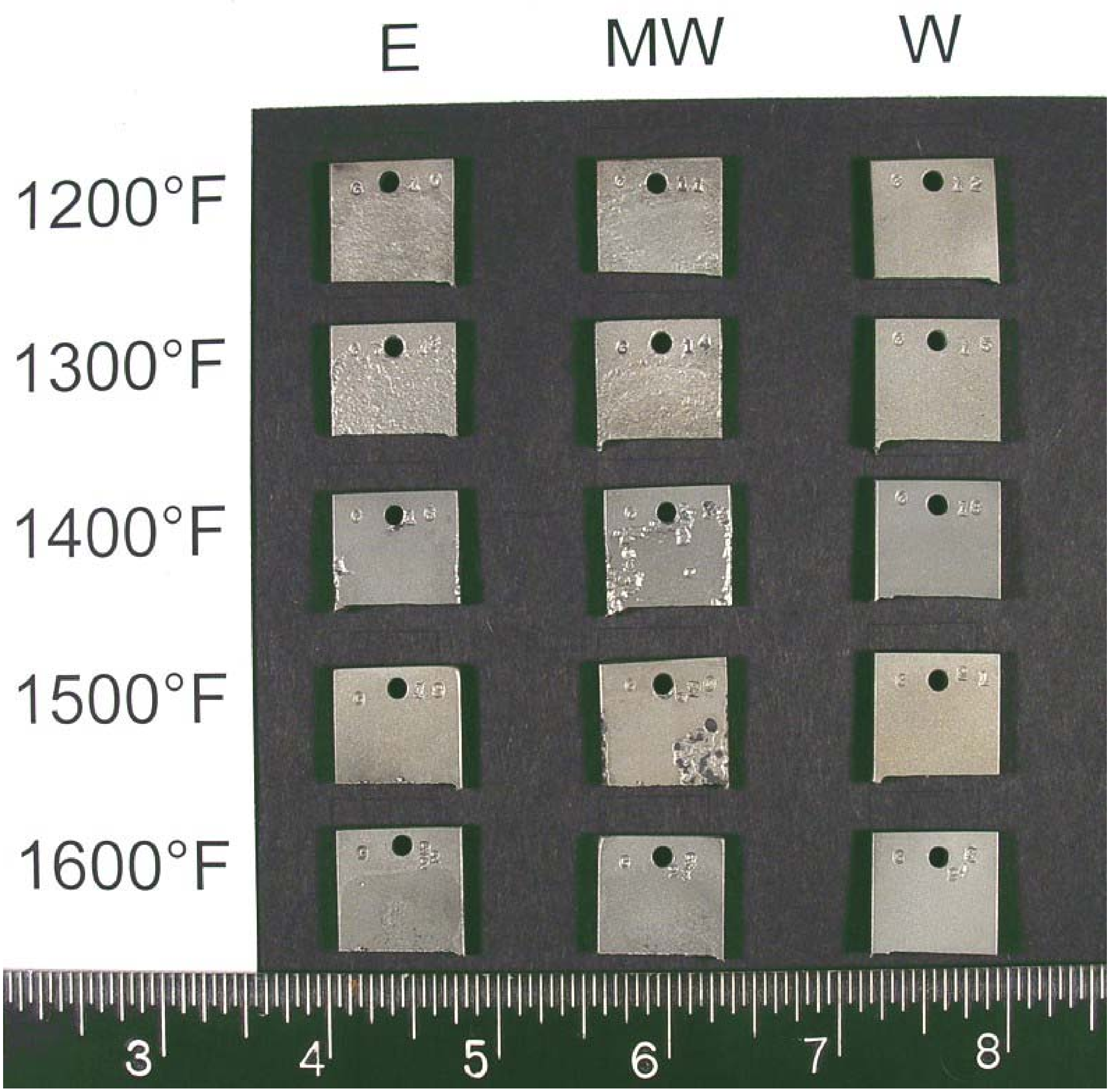


Figure 1

Macroscopic appearance of S304H specimens exposed in the superheater/reheater laboratory corrosion tests is displayed.

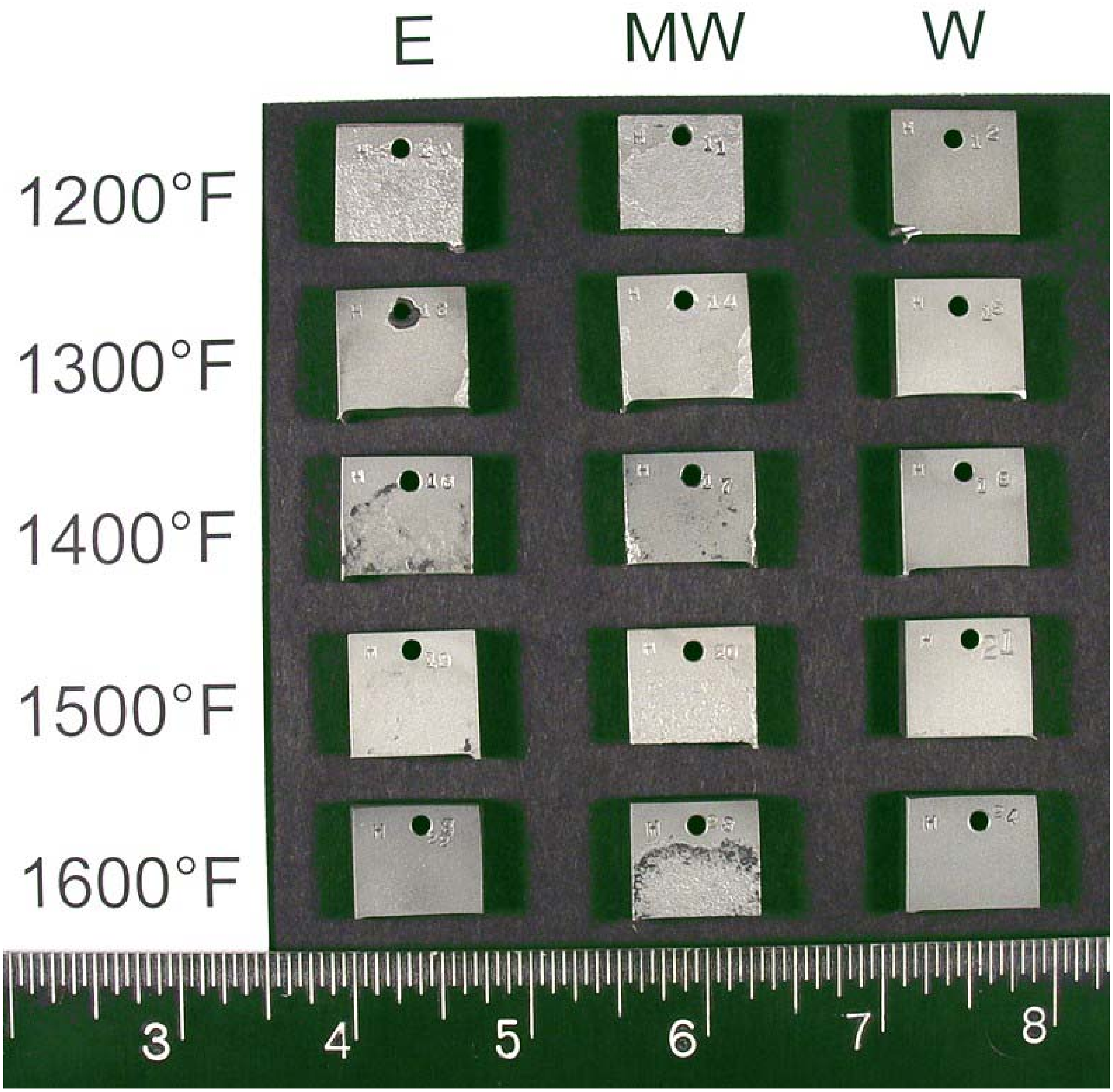


Figure 2

Macroscopic appearance of In-740 specimens exposed in the superheater/reheater laboratory corrosion tests is illustrated.

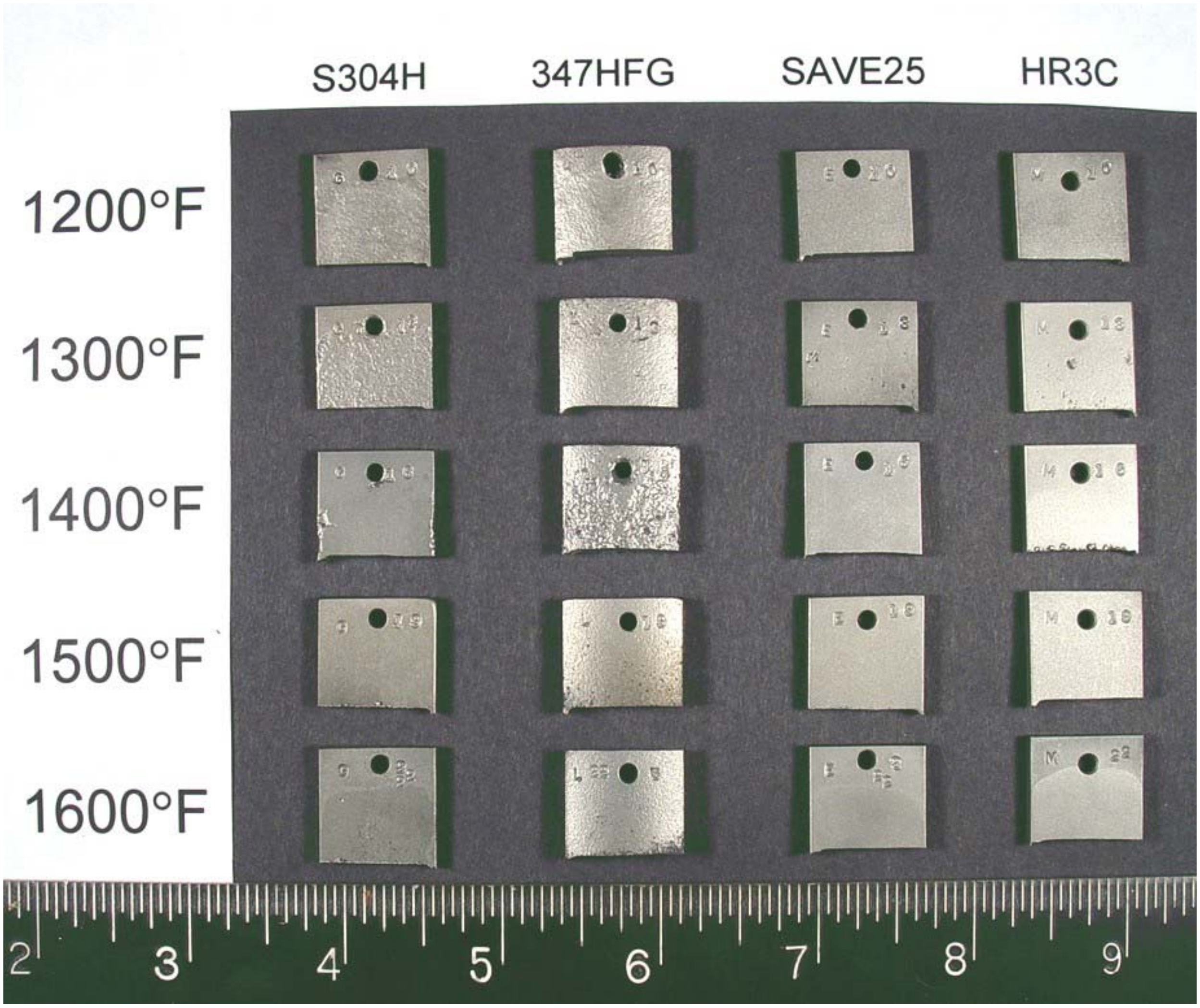


Figure 3

Comparison of the macroscopic appearance of various stainless steel specimens exposed to Eastern conditions in the superheater/reheater laboratory corrosion tests is shown.

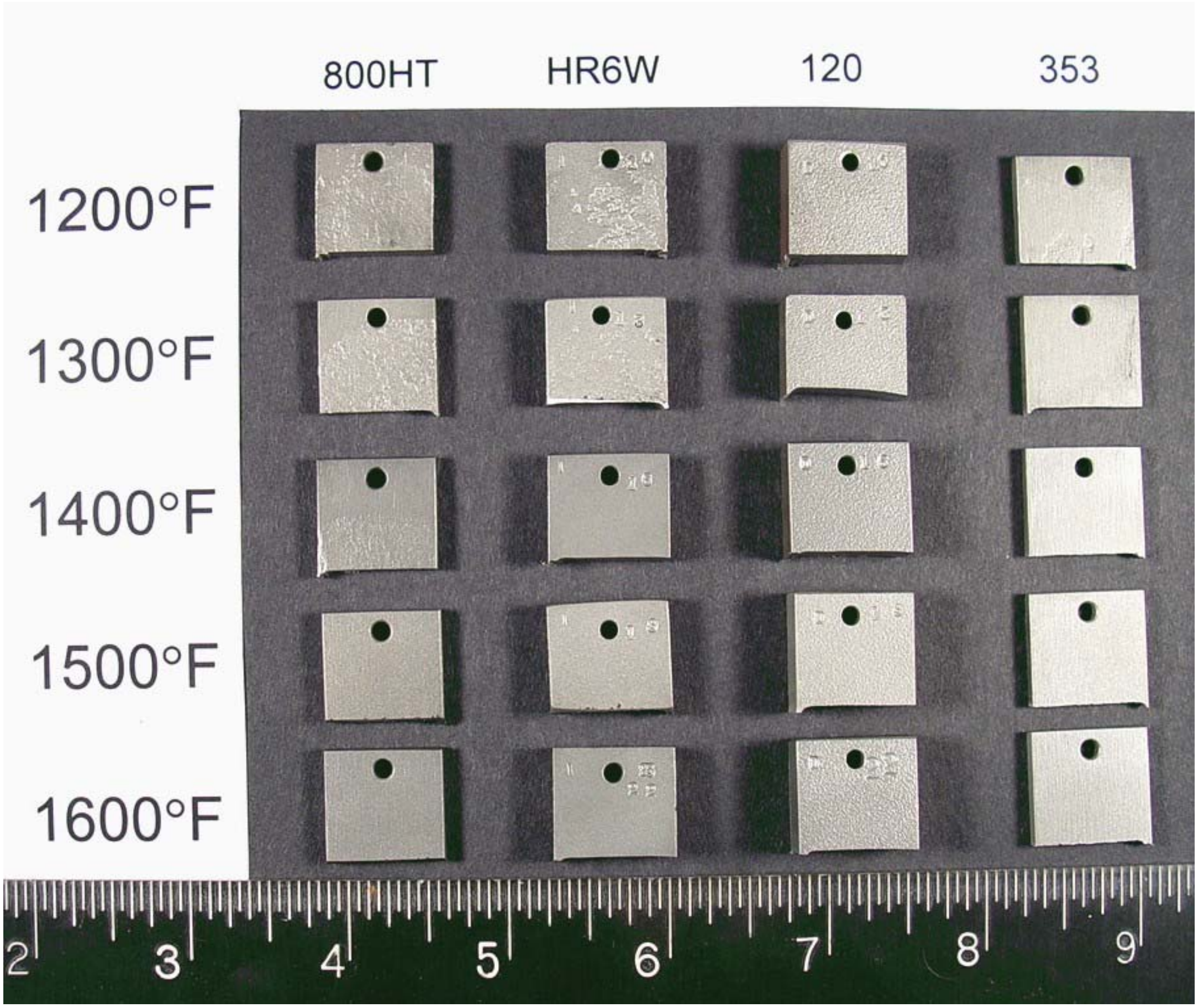


Figure 4

Comparison of the macroscopic appearance of Fe-Ni-Cr and Ni-Fe-Cr alloy specimens exposed to Eastern conditions in the superheater/reheater laboratory corrosion tests is presented.

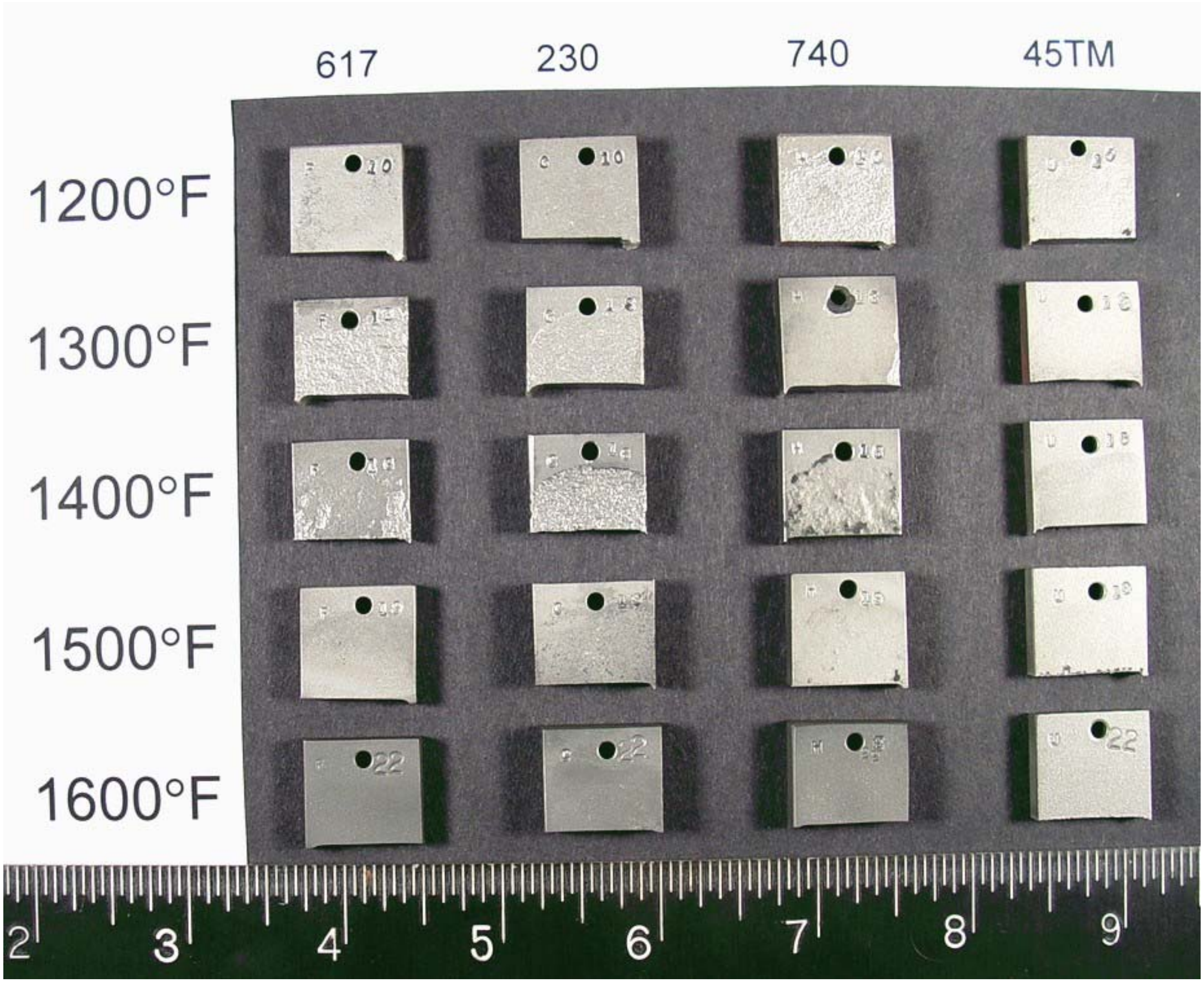


Figure 5

Comparison of the macroscopic appearance of high nickel alloy specimens exposed to Eastern conditions in the superheater/reheater laboratory corrosion tests is presented.

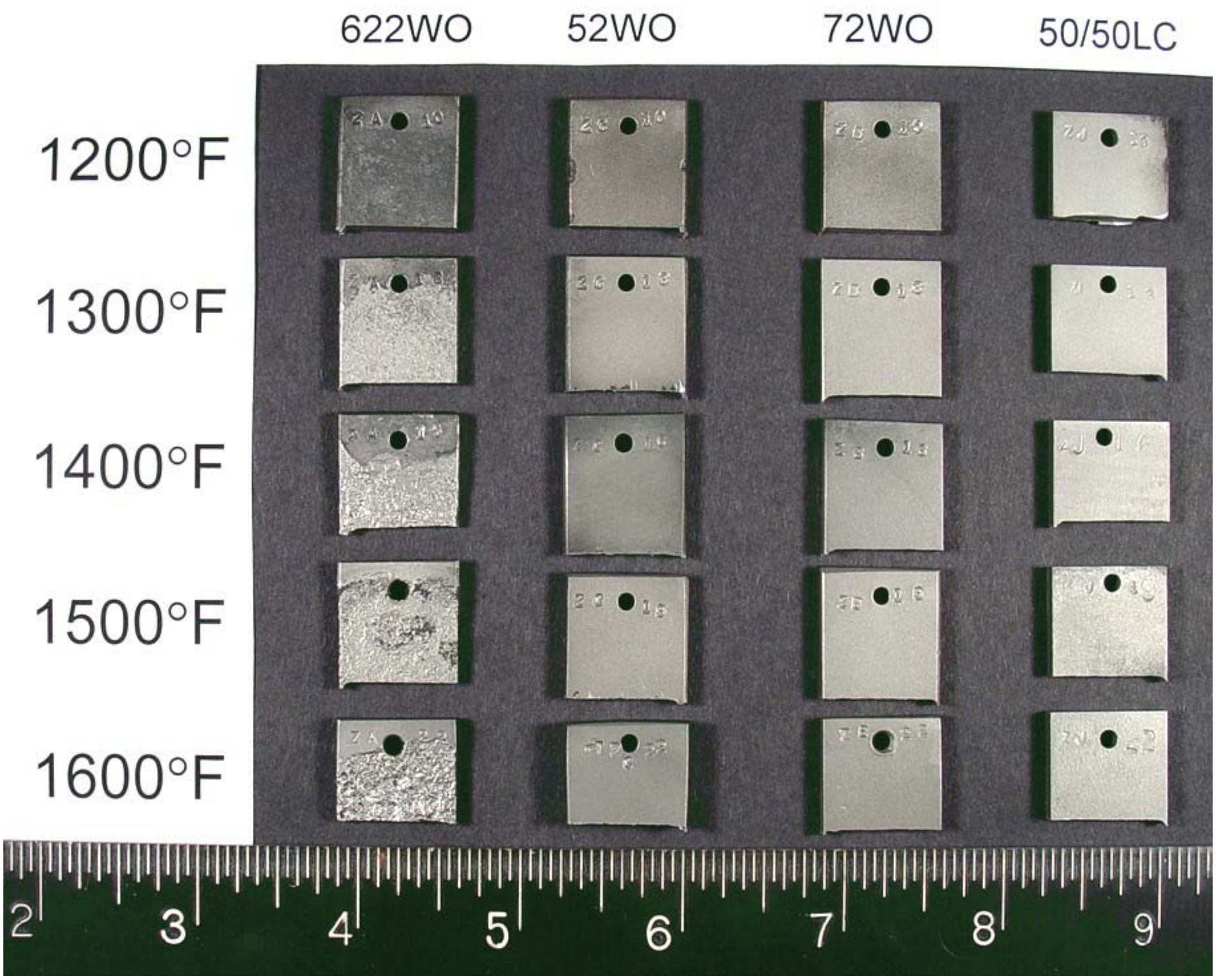
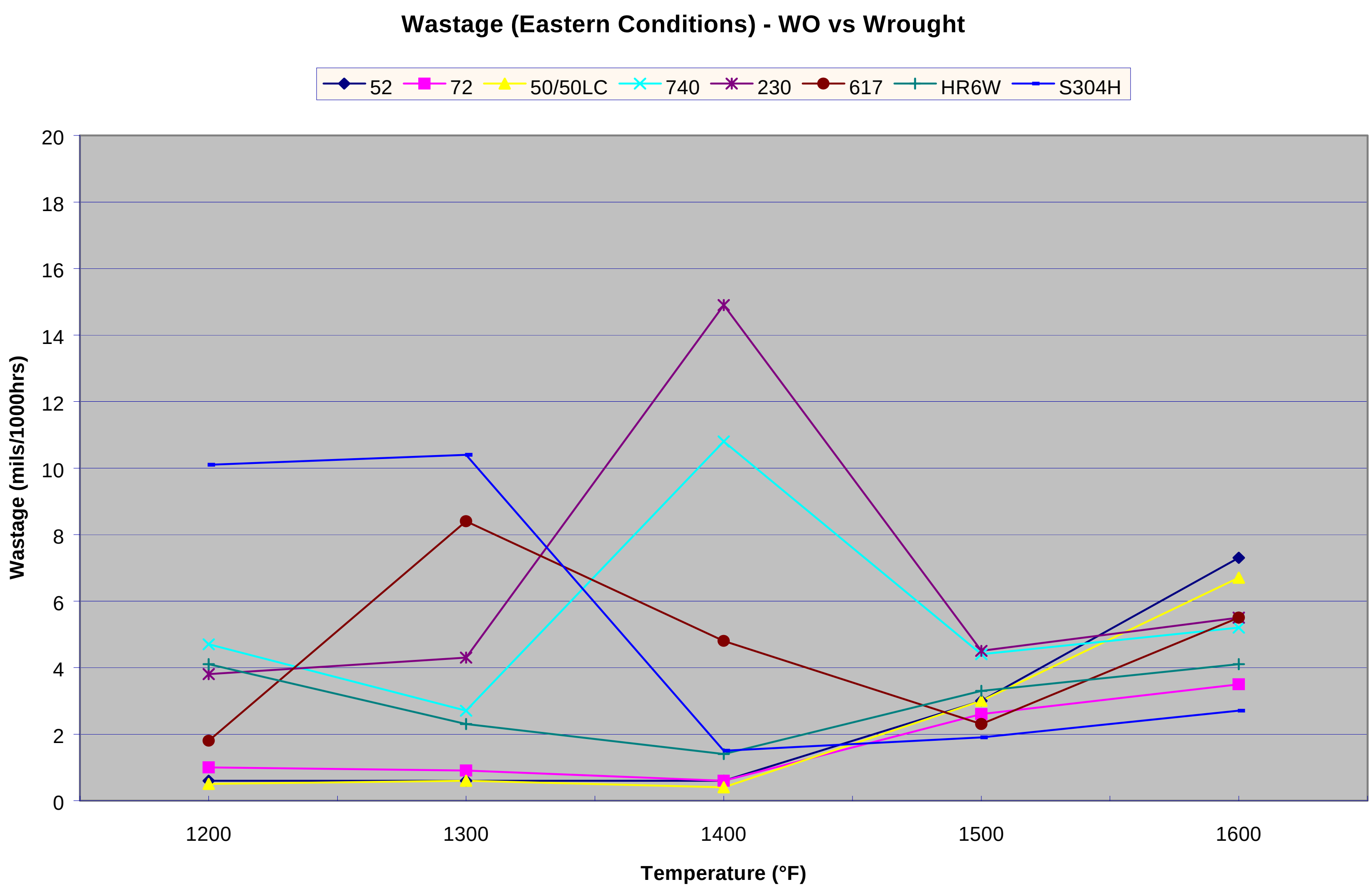


Figure 6

Comparison of the macroscopic appearance of weld overlay (WO) and 50/50 LC (laser clad) specimens exposed to Eastern conditions in the superheater/reheater laboratory tests is shown.



Graph of wastage versus temperature for five wrought alloys and three weld overlays/laser clad is presented for superheater/reheater specimens tested under Eastern conditions.

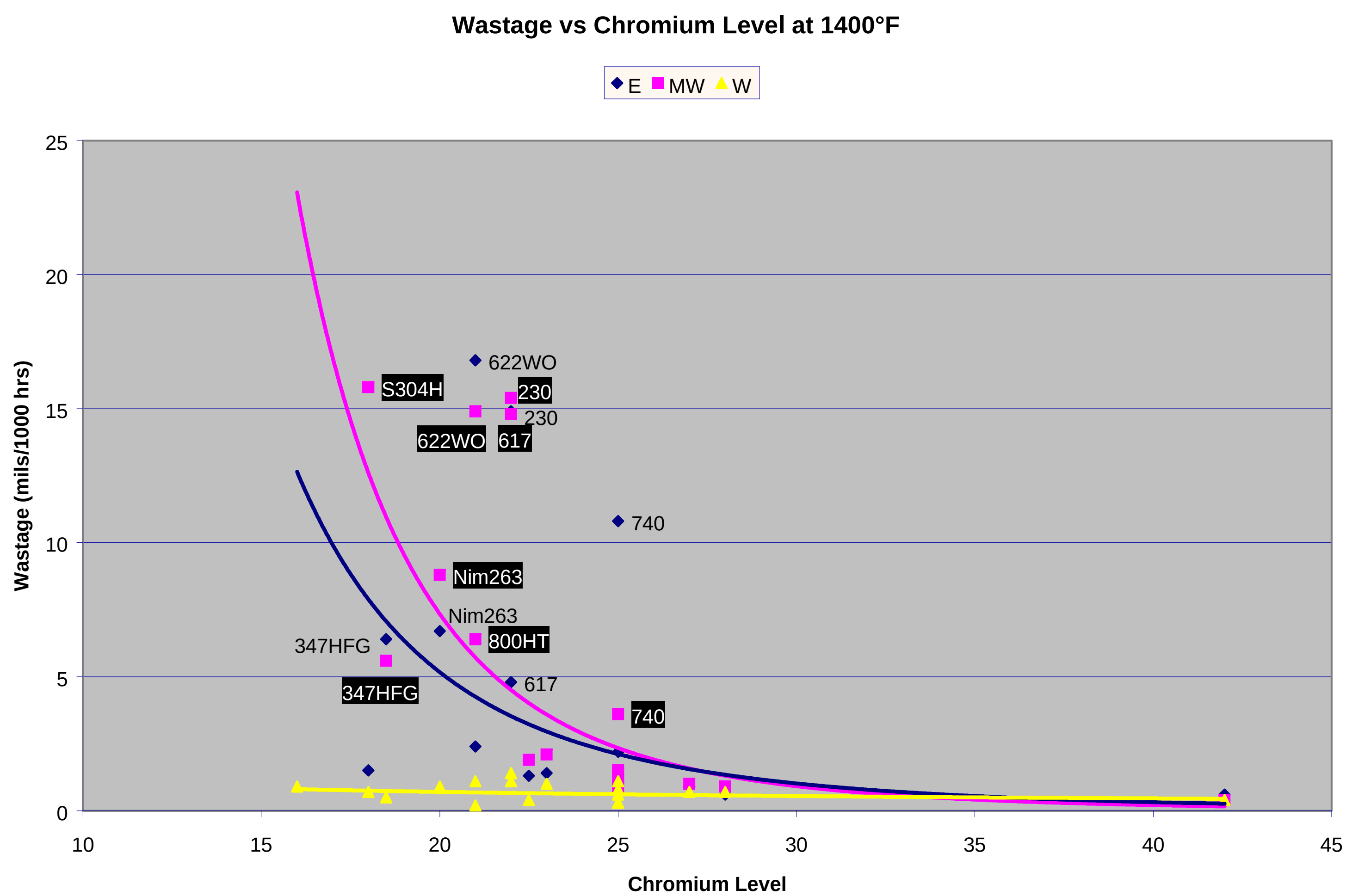


Figure 8

Graph of wastage versus chromium level is shown for superheater/reheater specimens tested at 1400°F.

Concerns:

No concerns at this time.

Plans for Next Quarter:

Continue to refine the results of the laboratory tests.

Task 4B Corrosion Probe Testing in Utility Boilers

Objective:

The objective of this sub-task is to install corrosion probes comprised of various alloys/coatings/weld overlays at three coal-fired power plants and control them in the temperature range expected for reheater/superheater components in the USC plant. The plants should burn coals representative of the three types specified earlier.

Experimental Progress:

- Fabrication and mechanical assembly of the probe retraction mechanisms for the third site have been completed.
- Data acquisition, instrumentation and control systems development has been completed and validation testing is under way.
- New supports have been designed to support the probes in the newly identified locations for the Mid-western fuel host site. Quotes have been received for electrical work needed to accommodate the new installation.
- Material samples for the probes been machined and final assembly of probes for the second and third sites is under way.
- Critical components have been delivered to the first and second host sites.
- Foster Wheeler continues to work closely with the host utility personnel to coordinate installation activities.
- Changes in fuel at our original Eastern coal host site have necessitated locating a new host site. Discussions were held with a new plant in Ohio to replace the original third host site.

Concerns:

The original third host site has indicated that their fuel is being changed to 100% low-sulfur PRB coal. This requires finding a new host site, firing a different coal (possibly

Eastern / PRB blend coal). Discussions are under way with First Energy to locate another possible host site within Ohio. It is likely that new penetrations will have to be added to the furnace wall to accommodate the corrosion probes. This will require rapid coordination with the plant to install the penetrations in the next short outage, in November.

Plans for Next Quarter:

- Complete mechanical and electrical modifications at the first host site.
- Finalize hosting arrangements and logistics for third host site.
- Complete the testing of instrumentation and controls systems for remaining probes.
- Complete final assembly of the remaining probes.
- Continue site installation tasks, coordinating with host utilities.
- Install probes and begin exposures at all host sites.

Task 4C Steam Loop Design, Construction, and Testing

Objectives:

The objectives of this sub-task are to design, build, and test an experimental USC steam loops that will operate in a commercial boiler at metal temperatures up to 1400ºF. The elements of this subtask include the following:

- Design and construct the test loop using commercially-available, high-temperature corrosion-resistant alloys selected for the USC Plant.
- Install and operate the test loop at the Reliant Electric power plant, which is located in Niles, OH and is burning high sulfur Ohio coal.
- Test and monitor the relative performance of the USC tube alloys, coatings, claddings, and weld overlays, which comprise the test loops, for a period of 18 to 24 months.

Experimental Progress:

- During July, Section B operated at temperature but Section A experienced control valve problems which did not permit it to operate in automatic mode. Plans were made to inspected and rebuild the valve as needed at the next opportunity. Currently the valve problem is prohibiting operation at the 1200F desired steam temperature. There is also some expectation that the use of over-fire air to reduce NOx during the ozone season, which also reduces flue gas temperature, may make the 1200F steam temperature more difficult to achieve.

- During a forced outage on August 14, a new I to P transmitter was replaced on the Section A control valve which corrected the operational problem. The unit was brought back on line on the 15th, both sections are now running properly and the 1200F steam temperature is being achieved. One of the safety valves is now leaking and a gasket will be replaced at the next opportunity.
- During September, the system operated as desired at full temperatures. The leaky safety valve gasket was replaced during the week of September 19th.

Plans for Next Quarter:

- Continue to operate at full temperatures.
- Continue to monitor operation and collect data.

Task 5
Welding Development
(Alstom)

Objectives:

- To define weld metal choices for candidate materials.
- To establish acceptable welding procedures and practices.
- To evaluate the effects of manufacturing heat treatments and preheat and post weld heat treatments on weldment integrity and properties.
- To produce samples needed to determine the properties of candidate ultrasupercritical alloy welds and weldments, including the dissimilar metal weld joints between the various types of material (the actual mechanical and property testing will be performed under Task 2).

These objectives will be accomplished through execution of five sub-tasks. Where activity on these sub-tasks occurred during the reporting period, it is described below.

Task 5B: Optimization of Weld Parameters

Objectives:

The primary objectives of this subtask are to establish the baseline welding parameter values for each material/process/product form combination being studied. Included is the development of preheat and post weld heat treatment requirements.

Progress for the Quarter:

<u>SAVE 12:</u>

- The SAVE12 heavy wall (13.78-inch OD x 2.3-inch wall pipe) qualification efforts continued and the arc instability problems in the submerged arc process are still being investigated.
- The alternate approach for thick-section welding, a flux core process with matching filler wire, was attempted twice. Although no welding difficulties were encountered in either instance, the first joint failed to pass radiographic testing in spite of reasonable cleaning efforts between all passes. Sectioning of the weld revealed that the radiographic indications had been caused by extremely fine slag inclusions; primarily along the weld pass fusion lines. Additional testing indicated that the post weld heat treatment procedure that had been established based on earlier chemical analysis

results was adequate and that cleanliness was the only issue. However, the second test, while passing the radiographic testing because of increased cleaning between passes, failed two out of four side bend tests. The bend failure areas had no obvious flaws but did not appear to be ductile, which prompted the fabrication of an all-weld metal coupon for tensile and Charpy impact testing. The results of the additional testing were not conclusive and the ALSTOM Materials Technology Center has been contacted for assistance.

Inconel 740:

- The Lincoln Electric pulsed gas metal arc welding techniques were continued at Special Metals on Inconel 740. Various diameter filler wires were utilized so that welding current and heat input could be varied. Lowering heat input caused less metal to be deposited per pass, thereby requiring more passes per weld joint, but microfissuring increased as the number of passes increased. This unexpected result prompted other approaches using different joint designs and slower travel speeds, which produced thicker beads. The results were better than those involving low heat input but the welds were not fissure free. However, the impact of the remaining fissures has not been determined and, perhaps, total elimination of fissures is not necessary.

- Two welds using 5/8-inch thick plate were made with a hot wire gas tungsten arc process and two different shielding gasses. These weldments had dramatically fewer microfissures than those made with the gas metal arc processes and more testing is planned.

- Special Metals produced their first experimental heat of Inconel 740 aimed at reducing microfissuring. The plan was to alter the chemical constituents within the current patented range for the alloy and the first trial reduced carbon from 0.030 to 0.015 wt% and niobium to 1.5%. Aluminum and titanium were balanced at 1.3% compared to the standard of 1.9% Ti and 0.9% Al. However, these adjustments did not reduce microfissuring and other heats will be produced with changes to the aluminum/titanium ratio and the boron content.

CCA 617:

Based on the information provided by UTP (the electrode supplier), welding trials were conducted to determine the minimum access requirements for shielded metal arc welding of CCA 617 plate with matching filler metal. Controlling and manipulating the welding arc proved to be very difficult and confining and this process was not considered practical for thick-section plate welding, at least with the electrodes currently supplied by UTP. Some accommodations can be made for out-of-position welding, but this process could not be released into a shop setting without significant application restrictions.

Super 304H:

B&W coordinated an attempt by Special Metals to make butt joints in Super 304H tubing using new gas metal arc welding equipment and procedures supplied by Lincoln Electric. Although the attempt was unsuccessful, Lincoln indicated that acceptable welds were still possible with minor procedure modifications. However, no plans were made for any additional testing and this issue is considered closed, at least within the current Task 5 scope of work.

Concerns:

- Submerged arc welding, a high deposition rate process favored by boilermakers for thick sections, does not appear feasible for all nickel base materials. Tests on Haynes 230 and Inconel 740 have been unsuccessful because of cracking and the process is being abandoned on these two alloys.
- The unexpectedly high cost of the nickel base alloys will cause the material budgets to be exceeded and might result in program cost overruns and/or reductions in program scope.
- The difficulties encountered while attempting to weld HR6W using matching filler metals proved insurmountable for this program and there will be no further effort in this area.
- Inconel 740 appears to have a heat-to-heat sensitivity with regards to microfissuring which could require additional constraints on composition.
- The use of matching filler metal for welding thick section CCA 617 plates does not appear practical.

Plans for the Next Quarter:

- Continue with the efforts to qualify the welding of the SAVE 12 thick wall pipe material. The ALSTOM Materials Technology Center in Chattanooga, TN has been contacted for further testing and a more detailed evaluation of the flux core and submerged arc welding problems.
- Continue to study the problems with heat affected zone microfissuring in Inconel 740 when using hot wire gas tungsten arc welding processes by evaluating the effect of joint geometry.
- Begin preparation of summary reports.

Task 5C: Preparation of Laboratory Samples

Objectives:

The primary objective of this subtask is to produce multiple samples representing each of the material/process/product form combinations being studied. These samples will be evaluated by ORNL as part of the Task 2 activities.

Progress for the Quarter:

Two sets of butt weld samples in the 2-inch diameter, 0.4-inch minimum wall thickness SAVE 12 tubing were completed and shipped to ORNL for evaluation. One set used a manual gas tungsten arc process throughout and Grade 92 filler; the other used a gas tungsten arc root and shielded metal arc fill processes with SAVE 12 custom filler.

Concerns:

None.

Plans for the Next Quarter:

- Using a process that has already been qualified, provide ORNL with a P92 pipe (6.3-inch OD x 1.1-inch wall) butt joint sample for testing.
- Provide ORNL with samples of butt welds in the 2-inch diameter, 0.4-inch minimum wall thickness SAVE 12 tubing that were made using a gas tungsten arc welding process and SAVE 12 custom filler.

Task 5D Weldability Testing

Objectives:

The primary objective of this subtask is to investigate any major weldability problems that arose during the weld procedure development efforts of Subtask 5C. The advertised properties of Inconel 740 made it an attractive material for use in an ultrasupercritical boiler, however significant welding issues were encountered which necessitated fundamental weldability studies before procedure development could continue. Edison Welding Institute was commissioned to conduct these studies and four specific objectives were identified:

1. Evaluate the heat affected zone liquation cracking susceptibility of Inconel 740.
2. Evaluate the heat affected zone ductility dip cracking susceptibility of Inconel 740.

3. Evaluate the post weld heat treatment cracking susceptibility of Inconel 740 and make a comparison with other common nickel-based precipitation-hardening alloys such as Inconel 718 and Waspaloy.
4. Evaluate the mechanical properties of Gleeble-simulated heat affected zones in Inconel 740 and of Inconel 740 welded plate joints in the post weld heat treated condition.

Progress for the Quarter:

With regards to the four objectives:

4. The full-scale (1-inch thick) Inconel 740 weldment was characterized and a report of the findings is being prepared.

Concerns:

None.

Plans for the Next Quarter:

Prepare a report documenting the mechanical characterization of the full-size weld joint.

Task 5E: Examination of Dissimilar Metal Welds

Objectives:

The primary objectives of this subtask are to develop and study the dissimilar metal welds that would be required to make transitions between the various alloys included in this program and the conventional materials that would also be used in an ultrasupercritical boiler.

Progress for the Quarter:

Dissimilar metal weld samples involving SAVE 12 and HR6W tubing were prepared and sent to ORNL for evaluation. The butt welds in the 2-inch diameter, 0.4-inch minimum wall thickness tubes utilized a manual gas tungsten arc process with Inconel 82 filler for the root pass and shielded metal arc welding with INCO A electrodes for the fill passes.

Concerns:

None.

Plans for the Next Quarter:

Fabricate samples of dissimilar metal joints between the HR6W and SAVE12 tubing using only gas tungsten arc welding for testing by ORNL.

Task 5: Welding Development - Milestone Chart

(DOE Fiscal Year Basis)
(percentages indicate fraction of workscope completed as of 2005Q4)

		Year 2002				Year 2003				Year 2004				Year 2005				Year 2006			
Task	**Milestone**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
5A	Selection of Weld Filler Material																				
	• Procure base metal for weld trials.	△					100%	▲													
	• Evaluation and selection of filler.	△					100%					▲									
	• Procurement of candidate fillers.	△					100%					▲									
5B	Optimization of Welding Parameters																				
	• Preliminary weld trials and parameter optimization – thin section.				△		95%											▲			
	• Preliminary weld trials and parameter optimization – thick section.				△		90%											▲			
5C	Preparation of Laboratory Samples																				
	• Material preparation.					△		90%										▲			
	• Sample fabrication.						△	90%										▲			
5D	Weldability Testing												△	90%				▲			
5E	Examination of Dissimilar Metal Welds.																				
	• Weld trials										△	60%						▲			
	• Metallurgical analysis											△ 0%						▲			
	• Analysis and test case.											△	0%					▲			

Task 6
Fabrication
(B & W)

Objectives:

The objective of Task 6 is to establish boiler fabrication guidelines for the high temperature, oxidation and corrosion resistant alloys selected for the USC Project. The principal goals in this joint effort are:

- To establish fabrication guidelines for the high temperature, corrosion resistant alloys needed for boiler components in the USC power plant.
- To determine the thermomechanical treatments or other remedial actions necessary to restore material properties which might degrade due to fabrication operations.
- To investigate prototypical manufacturing operations for producing both thick wall and thin wall components from the USC alloys.

Progress for the Quarter: Riley Power, Inc.

Riley Power has begun the preparation of summary reports on the history and accomplishments of the materials fabricability efforts. The format established by B&W will be used for the content and assembly of the report.

Concerns:

None.

Plans for the Next Quarter:

- After the recrystallization study results are available, Riley Power will determine the appropriate heat treatments applicable to the HR6W and SAVE12 materials, and additional samples of the materials may be sent to ORNL for testing.
- Riley Power Inc. is still considering the fabrication of a mock-up header / spool piece which would contain tubing components and welding of the HR6W and SAVE12 materials.

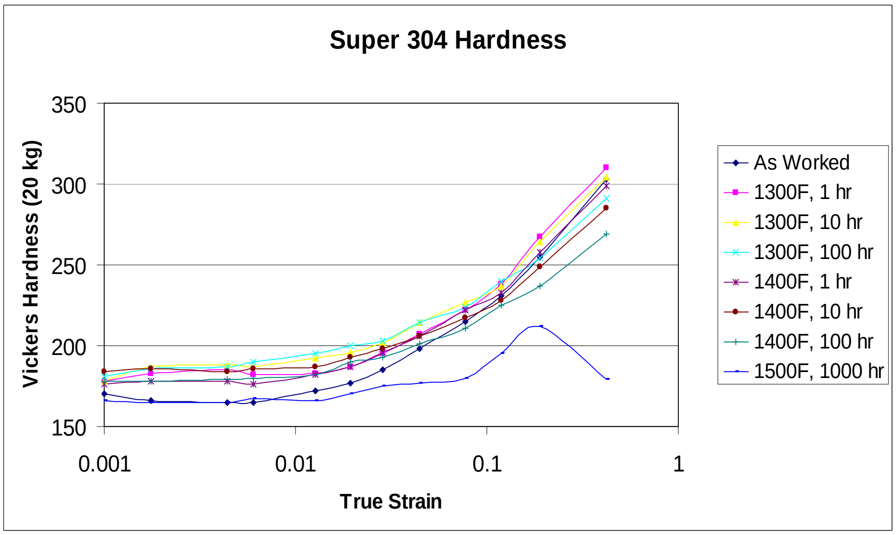
Progress for the Quarter: Alstom Power, Inc.

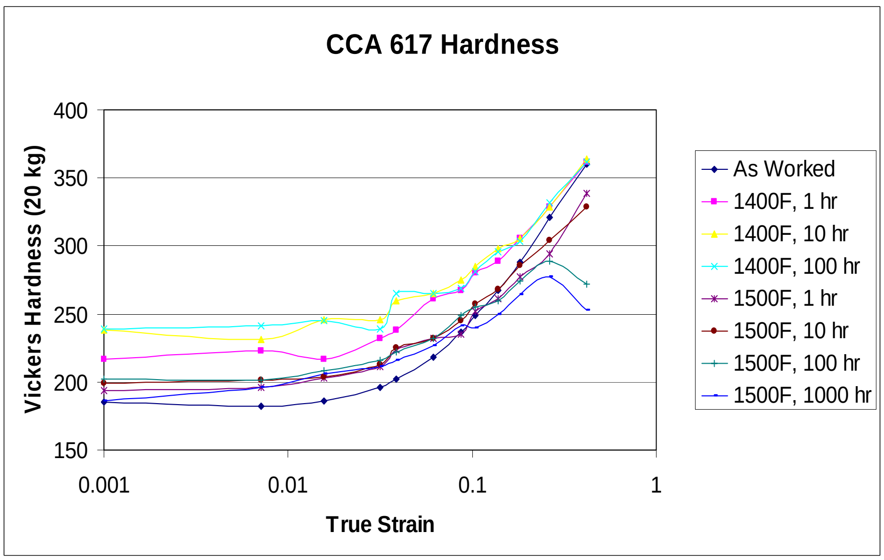
U-bend Specimens

- The 2-inch radius Super 304H hot bends had an intrados fold and will have to be remade.
- Destructive examinations have been started.

Tapered Tube Specimens

- Metallurgical examination of the tapered tube specimens prepared for the cold working studies was continued.
- No recrystallization was detected in the Super 304H at any strain level after heating samples at 1300 and 1400F for up to 100 hours and the onset of recrystallization was identified only at the highest strain level after 1000 hours at 1500F.
- The onset of recrystallization was detected in highly strained CCA 617 samples that had been heated at 1500F for 10 and 100 hours and holding for 1000 hours increased the degree of recrystallization but did not decrease the onset strain level.
- Another consequence of the aging at temperature was the formation and agglomeration of grain boundary and slip plane precipitates. The effects of the precipitation and recrystallization on hardness are illustrated in the following graphs.





Concerns:

No new concerns.

Plans for the Next Quarter:

- Remake the 2-inch radius Super 304H hot bends.
- Complete destructive examination of U-bend specimens.
- Continue the examination of the tapered tubes used for the cold working studies.
- Determine the sensitivity of Super 304H to strain induced embrittlement.

Progress for the Quarter: Foster Wheeler

Fabrication of IN740:

- Performed a dimensional analysis and hardness survey on the In-740 bends (6.75R, 5R, and 3R) that were made with the hard zone oriented at the extrados and intrados. The results were compared to the analysis and hardness survey performed on the bends made with the hard zone oriented at the neutral axis.
- The comparison of the results with regard to % ovality, % flattening, % thinning, % thickening, and maximum hardness at the center of the bend are presented in Table 1. A photograph illustrating the appearance of the cross sections at the center of the bend is shown in Figure 1. In only one case (in the 3R bend when the hard zone was oriented at the intrados) did the % ovality exceed the maximum allowed 8%. In all cases, the % flattening was below the maximum permitted amount.
- Prepared an estimate for bending In-740 tubes in the aged condition. The details of the estimate are given in Figure 2. The tubes will aged at 800°C (1472°F) for 4 hours and then bent to the following radii: 6.75 in. (14.8% OFS), 5 in. (20% OFS), and 3 in. (33.3% OFS).

Recrystallization Studies

- Performed a 1400°F/150 hour thermal exposure on the strained HR6W material. The samples were mounted for microscopic examination. They need to be evaluated to determine the strain level for the onset of recrystallization. The result will be used along with the data from the other exposures to plot % strain for onset of recrystallization vs Larson Miller parameter.

Concerns:

None.

Plans for the Next Quarter:

- Plans for next quarter are to do a microscopic analysis of the bends and perhaps try to bend some tubes that have been first subjected to an aging heat treatment.

Table 1

Summary of Dimensional Analysis of In-740 Bends with Respect to Orientation of Hard Zone

Orientation of Hard Zone	*% Ovality*			*% Flattening*			*% Thinning*			*% Thickening*			*Maximum Hardness HRC (HB)*		
	14.8[1]	*20*[2]	*33.3*[3]	*14.8*	*20*	*33.3*	*14.8*	*20*	*33.3*	*14.8*	*20*	*33.3*	*14.8*	*20*	*33.3*
Extrados	2.0	3.3	5.9	1.6	2.7	5.3	6.9	7.7	12.9	8.5	9.3	15.0	30 (286)	28 (271)	37 (344)
Neutral Axis	3.3	3.5	5.5	3.0	3.1	5.0	5.6	6.9	9.0	7.2	8.4	14.8	24 (247)	27 (264)	33 (311)
Intrados	3.0	4.7	9.1	2.7	4.3	8.8	3.8	8.3	15.5	5.7	8.5	15.6	25 (253)	34 (319)	34 (319)

[1] 14.8: 6.75R (3.38D)
[2] 20: 5R (2.5D)
[3] 33.3: 3R (1.5D)

Ovality Permitted: 8%
Flattening Permitted: 12 % - Below 2.5D
10% - 2.5D and Above

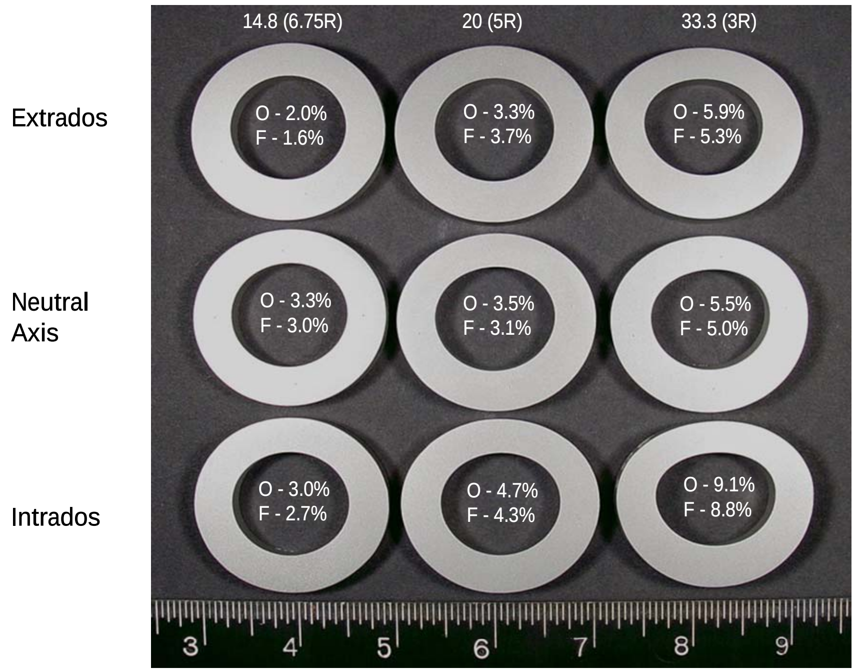


Figure 1. Cross-sections of IN740 U-bends

Bending of Aged In-740 Tubes (2.0 in. OD x 0.400 in. AW)

- Participants: Riley Power and Foster Wheeler
- Workscope:
  - Cut six lengths of straight tube (≈ 40in. long)
  - Perform aging heat treatment - 800°C (1472°F) for 4 hours
  - Bend two tubes each at the following radii:
    6.75 in. (14.8% strain), 5 in. (20% strain), and 3 in. (33.3% strain)
  - Perform dimensional analysis and hardness survey on one set
  - Send one set to ORNL for pressure testing
- Cost Estimate: $24,000.
  - Includes travel for a Riley Power representative and a FW representative to be at shop when bends are made
  - Does not include cost of testing at ORNL

Figure 2 Proposed workscope and cost estimate for conducting IN740 U-bends trials with age-hardened tube materials

Progress for the Quarter: B&W

- A proposed outline for the Task 6 final report was prepared and distributed to the consortium participants for review and comment.
- Preparation of B&W's contribution to the Task 6 final report was initiated.
- Alloy 230 tube samples, 2" OD by 8" long, that were machined to a 0.200" wall thickness were butt welded to 6' long carbon steel tubes (for positioning and handling) in preparation for swaging trials.
- Fabrication of Demonstration Article "A" (nested USC superheater loops) was nearly completed, as shown in the figure below.

Figure 1 Demonstration Article "A" (nested USC superheater loops) during fabrication. Cast 50Cr-50Ni attachments will be welded to the assembly and all materials used in fabrication will be identified for display.

Concerns:

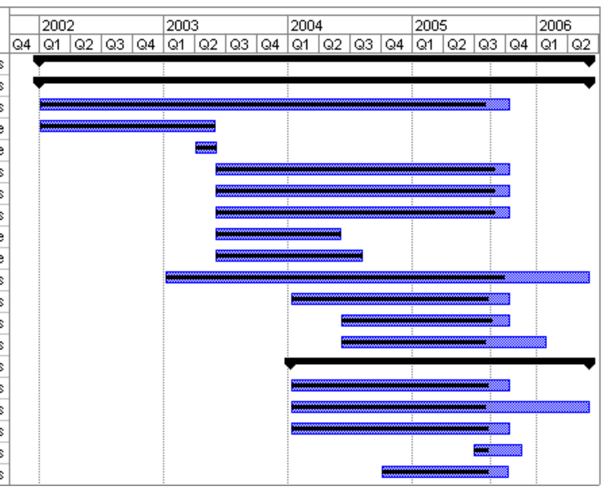
None.

Plans for the Next Quarter:

- Preparation of B&W's contribution to the final report will continue.
- Swaging trials with Alloy 230 tubes machined to 2" OD X 0.200MW are planned.
- Fabrication of Demonstration Article "A" (nested USC superheater loops) will be completed.
- Fabrication of Demonstration Article "B" (thick wall alloy 230 USC header section) will begin.

TABLE 6
Schedule and Progress

ID	Task Name	Start	Finish	Status
1	**Task 6: Fabricability**	Tue 1/1/02	Thu 6/1/06	In Progress
2	**6A: Fab Trials for SH**	Tue 1/1/02	Thu 6/1/06	In Progress
3	6A.1 SH Trial	Tue 1/1/02	Mon 10/10/05	In Progress
4	Procure Materials	Wed 1/2/02	Fri 5/30/03	Complete
5	Shop Sched & Graphics	Tue 4/1/03	Mon 6/2/03	Complete
6	Travel to Shop	Mon 6/2/03	Mon 10/10/05	In Progress
7	Cold Bending Trials	Mon 6/2/03	Mon 10/10/05	In Progress
8	Cold Swaging Trials	Mon 6/2/03	Mon 10/10/05	In Progress
9	Butt Welding Trials	Mon 6/2/03	Fri 6/4/04	Complete
10	Attachment Welding Trials	Mon 6/2/03	Fri 8/6/04	Complete
11	6A.2 Reporting	Fri 1/3/03	Thu 6/1/06	In Progress
12	6A.3 SH: Met Test & Eval	Fri 1/9/04	Mon 10/10/05	In Progress
13	6A.3.1 Mic Bends&Welds	Fri 6/4/04	Mon 10/10/05	In Progress
14	6A.3.2 HT Studies&Mic	Fri 6/4/04	Fri 1/27/06	In Progress
15	**6B: Fab Thk Wall Comp**	Fri 1/9/04	Thu 6/1/06	In Progress
16	6B.1 Thick-Wall Fab Trial	Fri 1/9/04	Mon 10/10/05	In Progress
17	6B.2 Reporting	Fri 1/9/04	Thu 6/1/06	In Progress
18	6B.3 Thick-Wall Comp	Fri 1/9/04	Mon 10/10/05	In Progress
19	6B.3.1 Met Analysis	Wed 6/29/05	Tue 11/15/05	In Progress
20	6B.3.2 PWHT Studies&Mic	Wed 9/29/04	Thu 10/6/05	In Progress



Task 7
Coatings
(Alstom)

Objectives for Task 7 Coatings:

- Review state-of-the-art of coating technology and identify development needs.
- Develop coating manufacturing techniques, which can provide corrosion/erosion protection for components in USC boilers, cost effectively.
- Establish manufacturing techniques for application of internal coatings for oxidation protection, cost effectively.
- Provide coated samples for corrosion and oxidation testing in the laboratory and "in the field".

These objectives will be accomplished through execution of eight sub-tasks. Where activity on these sub-tasks occurred during the reporting period, it is described below.

Task 7G: Manufacturing Guidelines

Objective:

Investigate the requirements for production coating of boiler materials.

Progress for the Quarter:

Work efforts for this task have concentrated on the requirements for diffusion-coating of the internal surface of boiler tubing. Further process details have been worked out to complete the selection and layout of equipment. A tentative layout is shown in Figures 1 and 2. An economic evaluation has been started to determine the costs involved in setting up a processing operation.

Concerns:

None.

Activities Planned for Next Quarter:

Complete the study of the manufacturing requirements and costs for coating of internal tube surfaces.

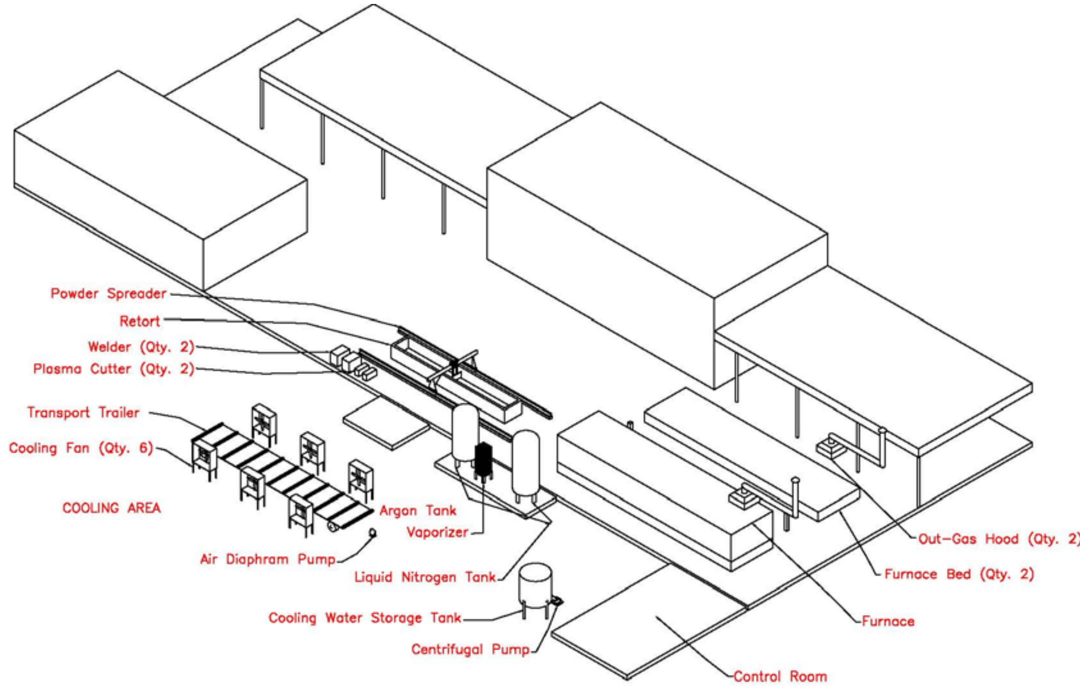


Figure 1: Equipment selection and layout of tube internal diffusion coating area.

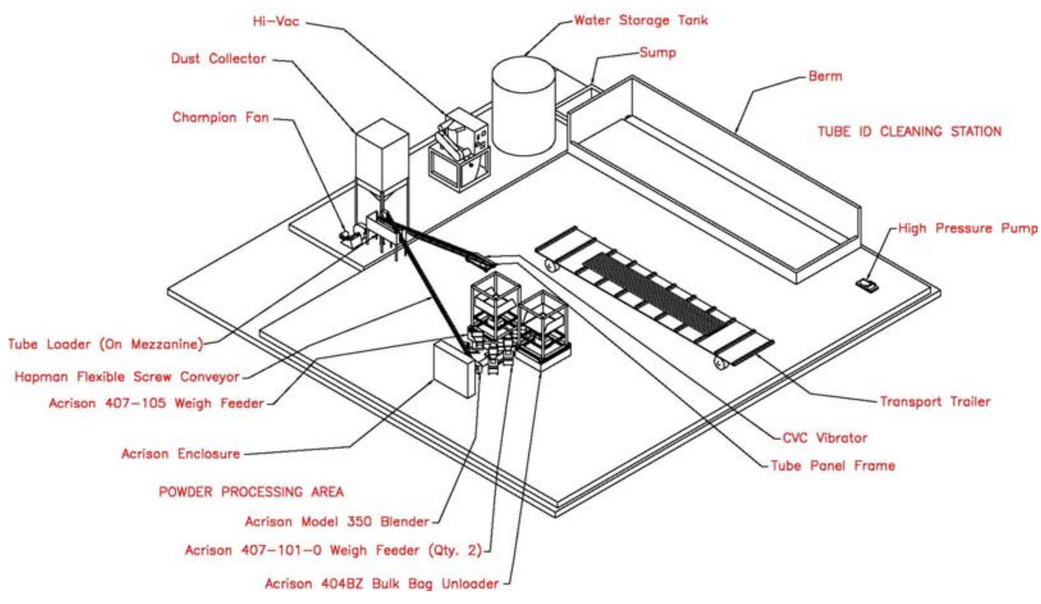
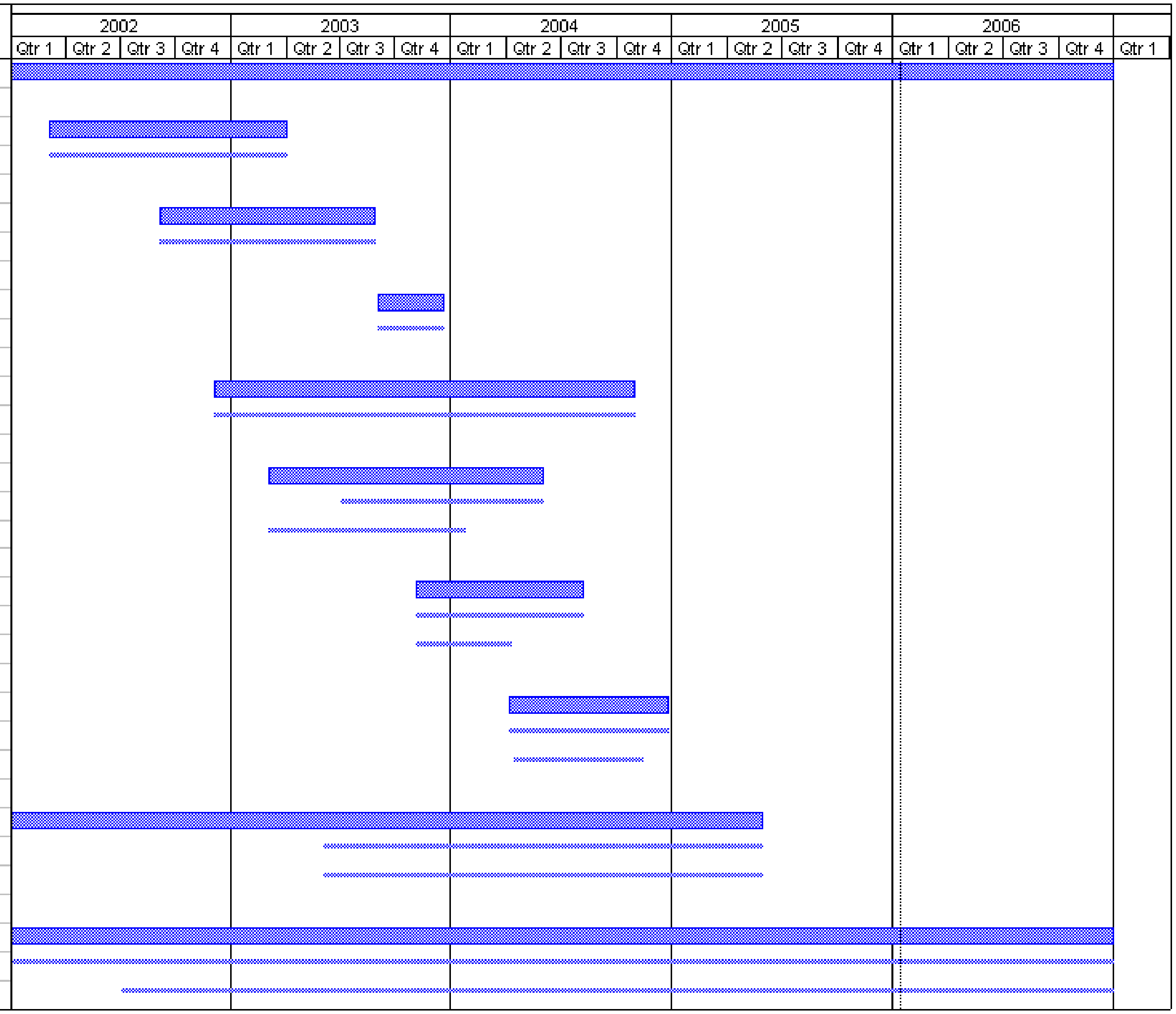
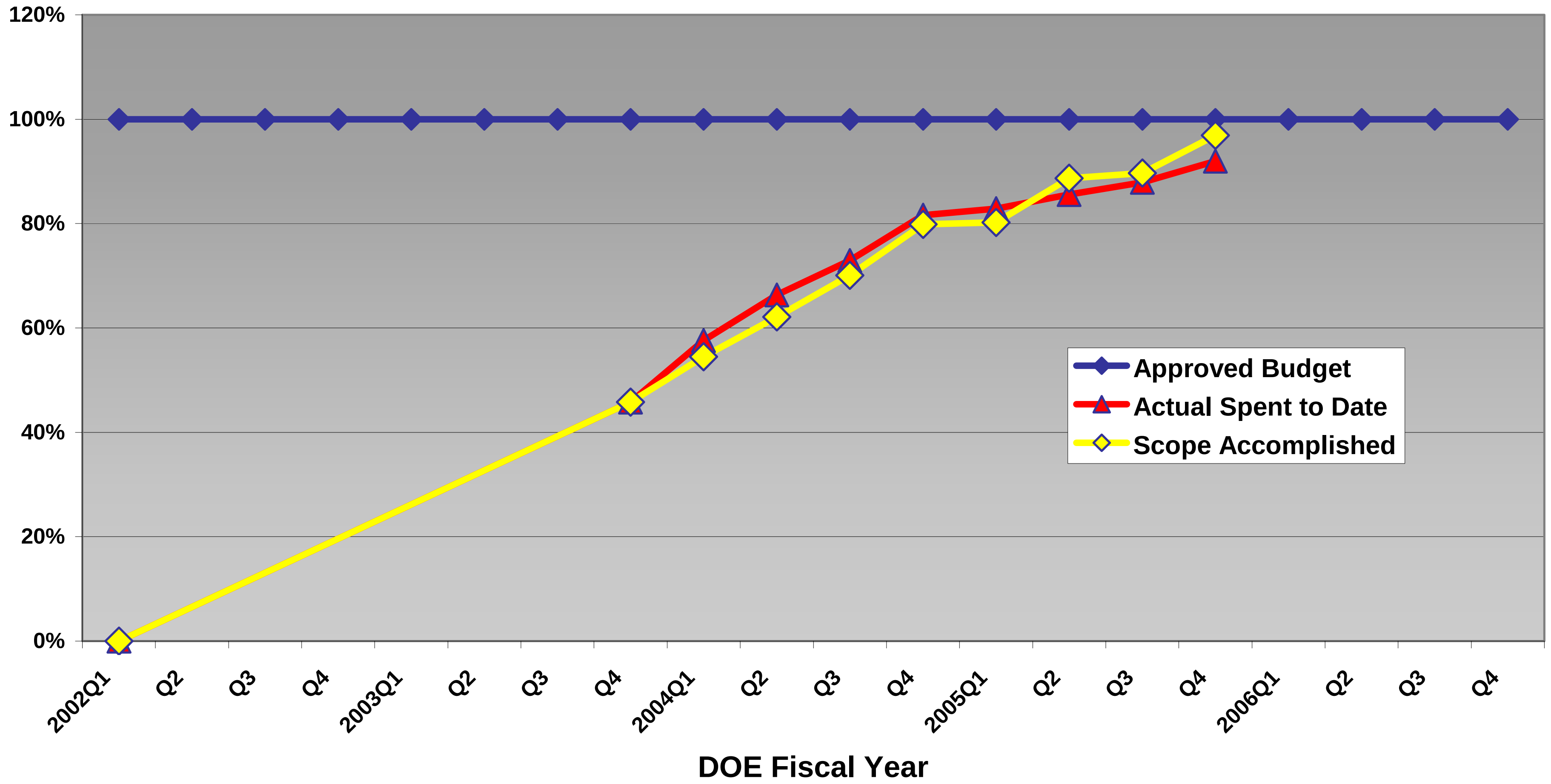


Figure 2: Equipment selection and layout of powder processing and tube cleaning area.

Task Name	Status
Task 7: Coatings	
Task 7A: Detailed Study of Current State of the Art	
Alstom Task 7A: Detailed Study of Current State of the Art	Complete
Task 7B: Coating Feasibility (Internal Coating)	
Alstom Task 7B: Coating Feasibility (Internal Coating)	Complete
Task 7C: Coating Recommendations	
Alstom Task 7C: Coating Recommendations	20%
Task 7D: Laboratory Testing	
Alstom Task 7D: Laboratory Testing	Complete
Task 7E: Process Scale Up - Preliminary Trials	
Alstom Task 7E: Process Scale Up - Preliminary Trials	Complete
B&W Task 7E: Process Scale Up - Preliminary Trials	Complete
Task 7F: Process Optimization	
Alstom Task 7F: Process Optimization	Complete
B&W Task 7F: Process Optimization	Complete
Task 7G: Manufacturing Recommendations	
Alstom Task 7G: Manufacturing Recommendations	95%
B&W Task 7G: Manufacturing Recommendations	
Task 7H: Specimens for Field Corrosion/Oxidation	
Alstom Task 7H: Specimens for Field Corrosion/Oxidation	Complete
B&W Task 7H: Specimens for Field Corrosion/Oxidation	Complete
Task 7I: Project Management	
Alstom Task 7I: Project Management	Ongoing
B&W Task 7I: Project Management	Ongoing



Scope Accomplished Versus Actual Expenditures
Task 7 Coatings Alstom Scope



Task 8
Design Methods and Data
(Alstom)

The major objectives for Task 8 are:

- Review the methods used by Section I of the ASME Boiler and Pressure Vessel Code to utilize materials properties and behavior models in the design of ultra-supercritical boilers.
- Develop and document methodologies whereby the results of the other tasks within this program may be most effectively applied within the ASME Section I design environment.
- Pursue the incorporation of such methodologies into Section I.

These objectives will be accomplished through execution of seven sub-tasks. Where activity on these sub-tasks occurred during the reporting period, it is described below.

Task 8A: Task Management (ALSTOM)

Objective:

The primary objective of this subtask is the overall management of the task, coordinating meetings and preparing progress reports.

Progress for the Quarter:

Progress continued to be rather slow. Limited material data availability and resource issues continue to hamper progress.

Concerns:

None.

Plans for the Next Quarter:

Continue general task management activities.

Task 8B: Material Data Collation and Processing (FW)

Objective:

The creation of documentation to ensure that quality test data is transferred between tasks and that this data remains traceable. A second objective is the analysis of such data with the objective of improving the statistical correlation. Foster Wheeler is subtask leader, with Riley Power Inc. providing significant input to this subtask.

Deliverables:

Item	Responsible	Status
Material data transfer sheets	ALSTOM	Transfer sheets provided for creep and tensile tests.
Electronic data repository	ORNL	Website complete.
Recommendations for statistical analysis of data		
Data compendia and fits for key materials		
Code case packages and submissions to code committees	ALL	

Progress for the Quarter:

Riley Power Inc. has continued to monitor the USC data transfer website for any added completed test results for the HR6W and SAVE 12 materials, assigned to Riley. During the quarter the results for the final creep rupture specimen tests for HR6W were posted on the website. Also, there remains one HR6W weldment in creep rupture testing. Riley has downloaded the latest test results, and is in the process of plotting them. Also, Riley has begun to prepare a summary report of the test results for the HR6W.

ALSTOM Power Inc. reviewed data on the USC data transfer site for CCA617 and Super304H. No base metal creep data was added in the quarter, but some weldment creep data was added for CCA617 and also for IN740. Comparison of base metal and crossweld creep rupture data for these alloys confirms the low weld metal strength with failures occurring in the weld metal in a significantly reduced failure time (more than an order of magnitude in failure time) than would be expected for base metal rupture. Indeed for IN740 the weld strength reduction factor is approximately 0.75, and for the single test on CCA617 the weld strength reduction factor is approximately 0.6. These significant strength reduction factors could have a severe impact on boiler design and highlight the importance of the weldment design and analysis portion of Task 8 (subtask F)..

Concerns:

None.

Plans for the Next Quarter:

The task participants will continue to monitor the USC data transfer web site for any additional, completed test results. Evaluations will continue to compare and contrast the strength of the materials with existing databases for similar alloys. It is projected that it will not be possible to work on statistical correlation of data for some time because of the lack of data on which to perform meaningful analysis. Support will be provided to Task 2, as needed, to address issues with additional structural feature tests, or interpretation of existing tests.

Task 8E: Continuum Damage Mechanics (B&W)

Objectives:

The objective of this subtask is to analyze uniaxial and multiaxial creep test data from Task 2 for several (three) materials to:

- establish the continuum damage mechanics (CDM) parameters,
- evaluate multi-axial strength theories and failure criteria,
- assess the implications of cyclic creep for USC materials,
- evaluate and compare CDM, reference stress and Omega models of typical ASME geometries.

Progress for the Quarter:

The continued scarcity of long-term creep data for the candidate materials means that the effort to model the creep response with continuum damage mechanics or other models remains on hold. Furthermore limited multiaxial creep rupture data are available (one notch bar test for IN740) so determination of the multiaxial stress rupture criterion cannot proceed.

Thermal cycling tests have begun at ORNL but few test details have been published. In addition, only one conventional LCF test result has been posted to the web-based data repository. When more basic LCF data is available, and details of the thermal cycling tests are published an effort will begin to model these tests.

In the meantime, the study has been completed to assess the cycling capability and margins against shakedown and ratcheting for a typical segment from a superheater header subject to normal cold startup and rapid cooling on shutdown. This compares the relative behavior of a typical region of a header made from a nickel-based alloy (CCA617), a stainless steel (S304H) and a ferritic steel (Grade 91). The analyses highlight the different behavior of the candidate materials when subject to similar transients. It is evident that Grade 91 is the most robust, followed by IN617 followed by Super304H. This ranking is identical to that from the preliminary assessment of the tolerance of the materials to thermal transients. The study demonstrates that modern analysis methods can be used to establish boundaries of component behavior that provide useful insight into the factors of safety and likely failure mode. The ability of this type of analysis approach to separate structural and material response has the potential to facilitate design for cyclic operation, which is consistent with the approach presently adopted within design codes for steady state operation. The results also highlight that for the selected geometry and materials, the margins against failure under cyclic conditions are quite different despite each configuration having roughly the same margin against creep rupture at steady operating conditions. Figure 1 shows a typical distribution of plastic strain from a cyclic analysis and Figure 2 shows a Bree diagram comparing the likely deformation modes for the candidate materials.

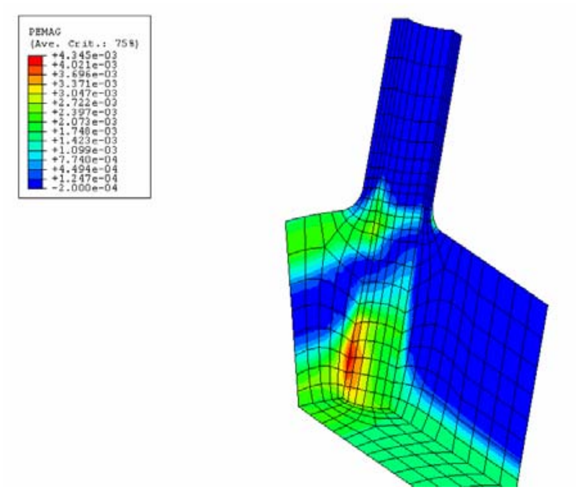


Figure 1. Plastic strain distribution after 10 cycles, indicating the existence of an "elastic core".

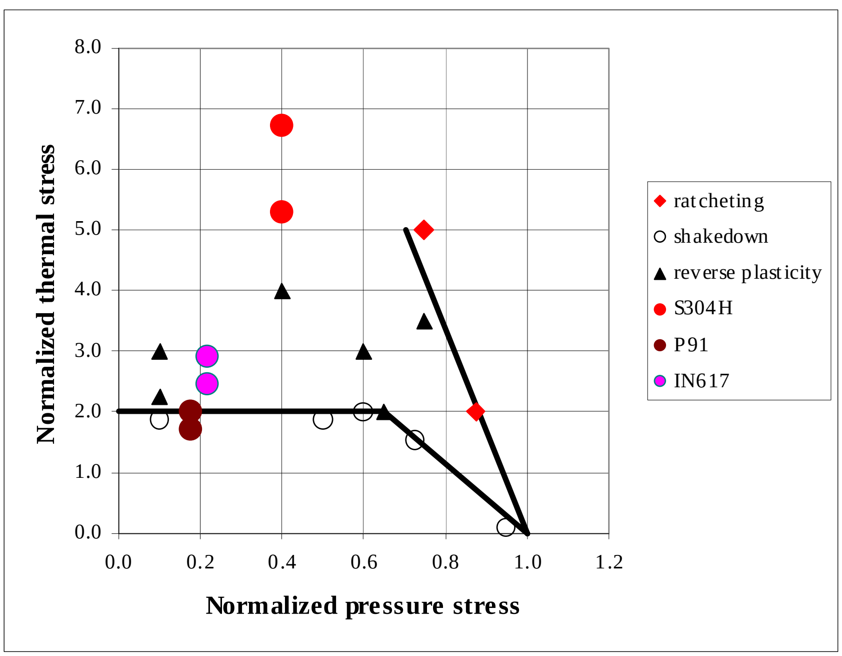


Figure 2. Generic interaction diagram and operating points for three materials (in-phase cyclic pressure and thermal load).

Concerns:

Timely availability of creep data on ORNL web site and results of notched bar creep rupture tests.

Plans for the Next Quarter:

Monitor material data web site to see if sufficient data is available to initiate a modeling activity. Check on status of structural feature tests. Issue topical report on the study comparing cycling capability of candidate alloys.

Task 8F: Weld Analysis and Assessment (ALSTOM)

Objective:

Create simplified analysis models of welds and heat affected zones (HAZ) utilizing material properties obtained from the open literature and from Task 2 to permit accurate creep life assessment of weldments.

Deliverables:

Item	Responsible	Status
Topical review of weld analysis and assessment in creep range.	ALSTOM & RPI	In progress.
Collation of material data for weld metal and HAZ.	RPI	In progress.
Creep models for weld metal and HAZ regions.	ALSTOM	In progress.
Report documenting the simulation of welded specimens and common Code geometries.	ALSTOM	
Report documenting the development and use of approximate weld assessment methods.	ALL	

Progress for the Quarter:

Riley Power Inc., submitted a memorandum to the subtask leader at Alstom Power Inc., describing the pertinent observations and findings from the completed review for simplified methods. This review, which was previously requested by the subtask leader, involved a second look at applicable weld literature documents, in order to determine the presence of any simplified scoping methods for use in finite element modeling. For example, methods using relative strengths between weld and base metals, or any commonality in ratios of numbers, such as varying creep rates between weldment regions. For simplification, the review was limited to the commonly used Grades 22 and 91 materials. ALSTOM made no further progress on the weld literature review.

Concerns:

None.

Plans for the Next Quarter

In the next quarter, ALSTOM will complete their portion of the weld literature review and work with Riley Power to issue the weld literature review summary report. Also, the weld creep rupture test data for nickel-based alloys will be compared and contrasted to help guide future modeling efforts.

Task 8G: Basic Design Rules for Cylinders (ALSTOM)

Objectives:

Review the various equations used by the ASME Code, Section I for Power Boilers to define the minimum thickness of cylinders under internal pressure and develop a single methodology applicable to ultrasupercritical boilers.

Deliverables:

Item	Responsible	Status
Report summarizing existing approaches and comparing and contrasting their predictions	ALSTOM	Complete (Aug 2003)
Report recommending a single equation with supporting theoretical data.	ALSTOM	Complete (Sept 2003)
Code case submission	ALSTOM	Complete (October 2003)

Progress for the Quarter:

No activity for this quarter.

Concerns:

None.

Plans for the Next Quarter:

None.

Task 9
Project Integration and Management
(EPRI)

- The objective of Task 9 is to coordinate the project and provide reporting to DOE and Ohio Coal Development Office (OCDO).

Progress for the Quarter:

- Completed Third Quarterly Report for 2005.
- Completed Monthly Reports for July and August, 2005.
- Monthly conference calls were held and the discussions were documented.
- Conducted Steering Meeting in Cleveland on August 31-September 1, 2005 and provided minutes.
- Overview presentations on the project were provided at the Welds conference in Hamburg and the ECCC conference in London.

Concerns:

- None

Plans for the Next Quarter:

- Issue monthly reports and hold conference calls as required.
- Arrange for Steering Committee Meeting in Charlotte on January 18th and 19th, 2006.