BOILER MATERIALS FOR ULTRASUPERCRITICAL COAL POWER PLANTS

U.S. DOE NO.: DE-FG26-01NT41175
OCDO NO.: D-00-20

First Quarterly Report for FY 2005
October 1 – December 31, 2004

Prepared by
R. Viswanathan
K. Coleman
J. Shingledecker
J. Sarver
G. Stanko
M. Borden
W. Mohn
S. Goodstine
I. Perrin

Submitted by
R. Viswanathan
K. Coleman

January 31, 2005

Participating Organizations

Alstom Power, Inc.
2000 Day Hill Road
Windsor, CT 06095

Riley Power Inc.
5 Neponset Street
Worcester, MA 01615

Foster Wheeler Development Corp.
12 Peach Tree Hill Road
Livingston, NJ 07039

McDermott Technology, Inc./
Babcock & Wilcox Company
1562 Beeson St.
Alliance, OH 44601

Electric Power Research Institute
(EPRI)
3412 Hillview Avenue
Palo Alto, CA 94303

The Energy Industries of Ohio, Inc.
Park Center One
6100 Oak Tree Boulevard
Independence, OH 44131

Oak Ridge National Labs
1, Bethel Valley Road
Oak Ridge, TN 37831

U.S. Department of Energy Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Project Consortium Legal Notice/Disclaimer

This report was prepared by the Energy Industries of Ohio in consortium with the Electric Power Research Institute, Inc. (EPRI); Alstom Power, Inc; Riley Power Inc.; Babcock & Wilcox/McDermott Technology, Inc.; and Foster Wheeler Development Corporation pursuant to a Grant partially funded by the U.S. Department of Energy (DOE) under Instrument Number DE-FG26-01NT41175 and the Ohio Coal Development Office/Ohio Air Quality Development Authority (OCDO/OAQDA) under Grant Agreement Number CDO/D-00-20. NO WARRANTY OR REPRESENTATION, EXPRESS OR IMPLIED, IS MADE WITH RESPECT TO THE ACCURACY, COMPLETENESS, AND/OR USEFULNESS OF INFORMATION CONTAINED IN THIS REPORT. FURTHER, NO WARRANTY OR REPRESENTATION, EXPRESS OR IMPLIED, IS MADE THAT THE USE OF ANY INFORMATION, APPARATUS, METHOD, OR PROCESS DISCLOSED IN THIS REPORT WILL NOT INFRINGE UPON PRIVATELY OWNED RIGHTS. FINALLY, NO LIABILITY IS ASSUMED WITH RESPECT TO THE USE OF, OR FOR DAMAGES RESULTING FROM THE USE OF, ANY INFORMATION, APPARATUS, METHOD OR PROCESS DISCLOSED IN THIS REPORT.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the Department of Energy and/or the State of Ohio; nor do the views and opinions of authors expressed herein necessarily state or reflect those of said governmental entities.

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). The project goal initially was to assess/develop materials technology that will enable achieving turbine throttle steam conditions of 760°C (1400°F)/35 MPa (5000 psi), although this goal for the main steam temperature had to be revised down to 732°C (1350°F), based on a preliminary assessment of material capabilities. The project is 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°C (1150°F) and nickel-based alloys suitable up to 700°C (1300°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, 2004.

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, and DOE's Vision 21. 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

- Held the EPRI Fourth International Conference on Advances in Materials Technology for Fossil Power Plants at the Hilton Oceanfront Resort in Hilton Head Island, SouthCarolina on October 26-28, 2004.

- Creep-Fatigue testing of CCA617 began this quarter and date to date appear to correlate well with published data.

- Creep testing of pressurized 230 and HR6W u-bends are close to 5000 hrs of testing time.

- Notched bar testing of IN 740 continues over 2000 hrs.

- The oxidation behavior of materials having greater than 12% Cr is less dependent on the Cr than materials having less than 12% Cr..

- Exfoliation rates were calculated for steam oxidation samples and data was presented.

- 1000 hr fireside corrosion tests were completed at 1100^{o}F and 1300^{o}F. Tests were started for 1400^{o}F test condition and have completed 900 hrs of exposure. Analyses of the 1300^{o}F and 1100^{o}F exposures were started.

- Conclusions were provided for superheater/reheater and waterwall corrosion.

- Fabrication of the first four air cooled probe assemblies has been completed. These probes included a redesign due to the results from the laboratory corrosion tests and fuel analysis from each host site.

- Susceptibility to microfissuring due to shielding gas and material chemistry were evaluated for IN 740.

- N 704 appears to be susceptible to ductility dip cracking and HAZ liquidation cracking.

- Investigation of dissimilar metal welds continues.

- A header mockup was completed and displayed at a recent conference. The mockup demonstrated bending, swaging, welding, and machining of CCA 617 and Super 304H and included dissimilar metal welds between these alloys and Grade 91 tubing. Several welding processes were demonstrated.

- Re-crystallization tests continued on Alloy 230 and the effect of time and temperature was evaluated.

- The new thickness/stress evaluation method which results in thinner section components at the high temperature/pressures of this program has made significant progress in ASME.

- An activity was started to analyze cyclic operation on ultrasupercritical boiler components manufactured from materials in this program.

E. Plans for the Next Quarter

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

- Microstructural investigation of aged IN 740 will continue with emphasis on the formation of eta phase.

- Samples of new materials will be added to the second oxidation exposure at 800^{o}C including NF709, 347W, shot-peened 347HFG and Super 304H, and Nimonic 283 filler metal.

- Gleeble simulated HAZ’s will be created to investigate mechanical properties of IN 704.

- Begin investigation of re-crystallization evaluation for HR6W and SAVE 12.

- Complete demonstration articles using other alloys.

F. Issues

- Many tasks are beginning to have problems with funding and work has slowed until additional funding is realized.

- The heat of Super HR6W currently under investigation does not meet expectations. The manufacturer believes this is because it is low in W. The manufacturer has agreed to send a new heat for evaluation.

- A significant drop in tensile strength in IN 740 is observed after aging at 800^{o}C for 300 hrs.

- Initial cross weld tests on some alloys show over an order of magnitude difference in creep life for weldments.

- A discrepancy exists between the B&W and ORNL oxidation testing reasons fr which are currently under investigation.

- Control problems continue on the steam cooled loops installed at the Niles plant that keep the loops from operating in the automatic mode at desired temperature.

- Construction of the last set of corrosion probes is on hold until incremental funding is released.

- Gas tungsten arc welding (GTAW) of SAVE 12 and HR6W using matching filler metals continue to demonstrate problems.

- The “Nanocomp” coating recently added to the program for analysis as a possible coating fell off samples during routine ash coating refreshing. The coating will be removed from further consideration.

- Correlation of creep rupture data for HR6W at higher temperatures indicate that the rupture life may be lower than expected. According to the manufacturer, this may be because of the Tungsten level.

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°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^oC (1200^oF) to 871^oC (1600^oF)
- Produce reports that justify the materials selected for the pressure retention components of the USC boiler

Progress for the Task:

Part I and II of the assessment report were published by EPRI and sent to all consortium members.

A task 2 summary report detailing the Task 2 progress and accomplishments (including a list of all papers, posters, and presentations) for calendar year 2004 was completed and sent to the program sponsors and management.

Four presentations and one poster were produced under Task 2 this quarter. They were.

- R.W. Swindeman, J.P. Shingledecker, R.L. Battiste, B.L. Sparks, R.L. Martin. "Experimental Work to Validate Alternate Design Methodologies for USC Steam Boiler Components." *Proceedings to the Fourth International Conference on Advances in Materials Technology for Fossil Power Plants (Oct. 25-28, 2004).* To be published by ASM/EPRI
- J. P. Shingledecker, R. W. Swindeman, Q. Wu, and V. K. Vasudevan. "Creep Strength of High-Temperature Alloys for Ultrasupercritical Steam Boilers." *Proceedings to the Fourth International Conference on Advances in Materials Technology for Fossil Power Plants (Oct. 25-28, 2004).* To be published by ASM/EPRI
- Q. Wu, V. K. Vasudevan, J. P. Shingledecker, and R.W. Swindeman. "Microstructural Characterization of Advanced Boiler Materials for Ultra Supercritical

Coal Power Plants." *Proceedings to the Fourth International Conference on Advances in Materials Technology for Fossil Power Plants (Oct. 25-28, 2004).* To be published by ASM/EPRI

- J. P. Shingledecker, R. W. Swindeman, V. K. Vasudevan, and Q. Wu. "High Temperature Strength Considerations for Ultrasupercritical Steam Boiler Materials." *Presentation: ASM Materials Solutions Conference*, Columbus, OH (October 18-20, 2004).

- J. P. Shingledecker, R. W. Swindeman, I. G. Wright, R. R. Judkins, P. J. Maziasz, R. L. Klueh, and R. L. Battiste. "Materials for Ultra-Supercritical Steam Power Plants. *Poster Presentation: ASM Materials Solutions Conference*, Columbus, OH (October 18-20, 2004)

Task 2B: Detailed Test Plan

Progress:

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. Progress and/or problems associated with the welding (Task 5) and fabrication (Task 6) tasks will determine testing specifics. Thus, to some measure the test plan continues to evolve. The testing plans for the thick-section materials, SAVE 12, CCA617, Alloy 230, and Inconel 740 are still under development. A test matrix for the fatigue testing on CCA 617 has been designed. Discussions with Task 8 members have helped define the structural tests needed by the boiler manufacturers to evaluate their respective component models. Further input from Task 8 will help determine specific test conditions.

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. The characterization testing plans have been completed for creep-rupture testing of the five tubing alloys (Super 304H, HR6W, alloy 230, CCA617, and INCONEL 740). Minimal testing is required for Super 304H and Hayes 230 as their creep-rupture database was judged to be adequate, since both materials are code alloys. A test plan for INCONEL 740 tubing has been designed. Priority has been given to producing a database for the INCONEL 740 tubing. These data will provide creep/creep-rupture data needed to produce a code case on the material. To fabricate thick plate weldments of 740, it may be necessary to overage the base material prior to welding. It is anticipated that this heat treatment will alter the creep strength of the alloy and thus design of the test matrix for the thick section 740 will be completed after welding trials are complete.

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 for five tubing alloys currently in testing is provided in the tables below. In each table, comparison of the rupture lives may be made with the expected life based on prior data and extrapolation of reported properties. The initial results indicate that the strength of the Super 304H and alloy 230 are meeting expectations, while the HR6W is below expectations. As previously discussed, Sumitomo believes the poor creep strength is due to low W in the consortium heat, but this has yet to verified by ORNL. Sumitomo has agreed to send material from a new heat of HR6W to ORNL for evaluation. The CCA617 alloy is exceeding expectations in the lower temperature regime (650°C to 700°C), based on performance equivalent to alloy 617. Larson-Miller-Parameter extrapolation shows the creep strength benefit may extend to 750°C for

CCA617 vs. std. 617. Additional short-term tests have been added to the CCA617 test matrix. All of the planned Super 304H and HR6W creep-rupture tests are in progress. Testing is progressing on the INCONEL 740 tubing. 100 and 1000 hours rupture lives appear close to predictions based off previous work at ORNL and data from Special Metals. An isothermal plot at the end of the section shows the predicted 740 behavior based off extrapolation from ORNL and Special Metals data. These data are close to the original estimates and are not based-off the reduced creep-strength values reported elsewhere.

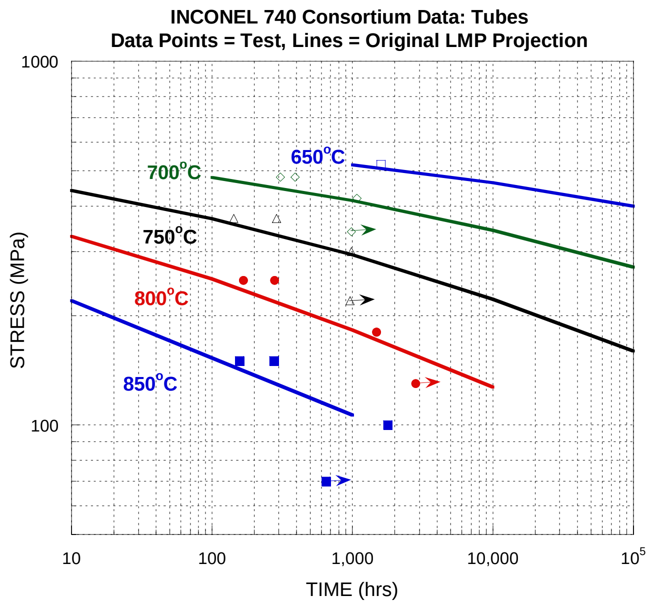
Creep-Rupture Testing of Super 304 H (Case Code 2328)						
Spec #	**Test #**	**Stress (MPa)**	**Temp. (ºC)**	**Estimated Life**	**Date Started**	**Life (hrs)**
SM-01	30298	240	600°C	10000 Hrs	6/11/2003	
SM-02	30299	280	600°C	1000 Hrs	6/11/2003	10083.2
SM-03	30383	340	600°C	100 Hrs	12/1/2003	864.6
SM-04	30293	120	650°C	10000 Hrs	6/3/2003	
SM-05	30292	210	650°C	1000 Hrs	6/3/2003	2240
SM-06	30372	260	650°C	100 Hrs	10/21/2003	412
SM-07	30377	110	700°C	10000 Hrs	11/24/2003	
SM-08	30294	160	700°C	1000 Hrs	6/3/2003	1011.5
SM-09	30384	210	700°C	100 Hrs	12/2/2003	106.2

Creep-Rupture Testing of HR-6W (Heat #DZC1309)						
Spec #	**Test #**	**Stress (MPa)**	**Temp. (ºC)**	**Estimated Life**	**Date Started**	**Life (hrs)**
HR-6W-01	30282	200	650	1000	5/21/2003	921.1
HR-6W-02	30315	175	650	6000	7/2/2003	2194.2
HR-6W-03	30330	150	650	20000	7/31/2003	5167.1
		~~200~~	~~675~~	~~500~~		
		~~170~~	~~675~~	~~1000~~		
		~~150~~	~~675~~	~~6000~~		
		~~200~~	~~700~~	~~50~~		
HR-6W-08	30426	100	700	15000	3/15/2004	
HR-6W-09	30317	150	700	1000	7/9/2003	451.3
HR-6W-10	30325	120	700	10000	7/22/2003	2056.7
HR-6W-11	30368	100	725	10000	10/14/2003	2663.2
HR-6W-12	30283	150	725	500	5/21/2003	187.5
HR-6W-13	30291	120	725	5000	6/2/2003	723.8
		~~140~~	~~750~~	~~100~~		
HR-6W-15	30405	120	750	500	2/2/2004	202.5
HR-6W-16	30425	100	750	5000	3/15/2004	844.1
HR-6W-04	30424	85	750	20000	3/15/2004	2740.2
HR-6W-05	30396	100	775	600	12/29/2003	225
HR-6W-06	30401	85	775	5000	1/14/2004	713.6
HR-6W-07	30395	100	800	150	12/29/2003	80.24
HR-6W-14	30427	85	800	1000	3/15/2004	251.8

Creep-Rupture Testing of Haynes 230						
Spec #	**Test #**	**Stress (MPa)**	**Temp. (ºC)**	**Expected Life**	**Date Started**	**Life (hrs)**
H230-01	30302	**350**	**650**	200	6/16/2003	410.8
H230-02	30306	**300**	**650**	1000	6/18/2003	1071.4
H230-03		**200**	**650**	10000		
H230-04		**300**	**700**	100		
H230-05	30301	**200**	**700**	1500	6/12/2003	1517.1
H230-06		**140**	**700**	15000		
H230-07		**200**	**750**	100		
H230-08	30399	**140**	**750**	2000	1/6/2004	1501
H230-09	30402	**100**	**750**	15000	1/20/2004	
H230-10	30373	**140**	**800**	100	Test Discontinued	
H230-11	30300	**100**	**800**	2000	6/11/2003	2101.2
H230-12		**80**	**800**	20000		
H230-13	30375	**140**	**800**	100	11/3/2003	169.2

Creep-Rupture Testing of CCA617						
Spec #	**Test #**	**Stress (Mpa)**	**Temp. (ºC)**	**Estimated Life**	**Date Started**	**Life (hrs)**
617-01	30303	**350**	**650**	200	6/16/2003	8242.0
617-02	30305	**300**	**650**	1000	6/18/2003	
617-03	30357	**200**	**650**	10000	9/16/2003	
617-04	30337	**300**	**700**	100	8/19/2003	2376.8
617-05	30318	**200**	**700**	1500	7/9/2003	
617-06		**140**	**700**	15000		
617-07	30363	**200**	**750**	100	9/30/2003	1561.8
617-08	30388	**140**	**750**	2000	12/8/2003	
617-09		**100**	**750**	15000		
617-10	30331	**140**	**800**	100	8/6/2003	329.9
617-11	30343	**100**	**800**	2000	9/3/2003	1831.0
617-12		**80**	**800**	20000		
617-13	30352	**400**	**650**	200	9/10/2003	1279.7
617-14	30387	**400**	**700**	100	12/3/2003	301.6
617-15		**300**	**750**	100		

Creep-Rupture Testing of INCONEL 740 (Heat # CLH4663) - Aged 16hrs, 800C, Ar								
Spec #	**Product Form**	**SA Temp(C)**	**Test #**	**Stress (MPa)**	**Temp. (°C)**	**Expected Life**	**Date Started**	**Life (hrs)**
740-01	Tube	1120	30443	**480**	**700**	100	4/13/2004	308
740-02	Tube	1120	30448	**370**	**750**	100	5/4/2004	142.8
740-03	Tube	1120	30455	**250**	**800**	100	5/17/2004	167.5
740-04	Tube	1120	30461	**150**	**850**	100	5/26/2004	157.1
740-05	Tube	1120						
740-06	Tube	1120						
740-07	Tube	1120						
740-08	Tube	1120						
R740-01	Tube	1190		**580**	**650**	100		
R740-02	Tube	1190	30437	**520**	**650**	1000	3/29/2004	1599.6
R740-03	Tube	1190		**465**	**650**	10000		
R740-04	Tube	1190	30472	**480**	**700**	100	7/7/2004	392.6
R740-05	Tube	1190	30492	**420**	**700**	1000	9/15/2004	1082.2
R740-06	Tube	1190	30507	**340**	**700**	10000	10/20/2004	
R740-07	Tube	1190	30464	**370**	**750**	100	6/7/2004	289.3
R740-08	Tube	1190	30467	**300**	**750**	1000	6/11/2004	984.5
R740-09	Tube	1190	30509	**220**	**750**	10000	10/21/2004	
R740-10	Tube	1190	30449	**250**	**800**	100	5/4/2004	279.2
R740-11	Tube	1190	30439	**180**	**800**	1000	3/30/2004	1491.1
R740-12	Tube	1190	30476	**130**	**800**	10000	8/4/2004	
R740-13	Tube	1190	30463	**150**	**850**	100	6/1/2004	275.6
R740-14	Tube	1190	30457	**100**	**850**	1000	5/19/2004	1789.4
R740-15	Tube	1190	30514	**70**	**850**	10000	11/3/2004	



Task 2D: Microstructural Analysis

Objective:

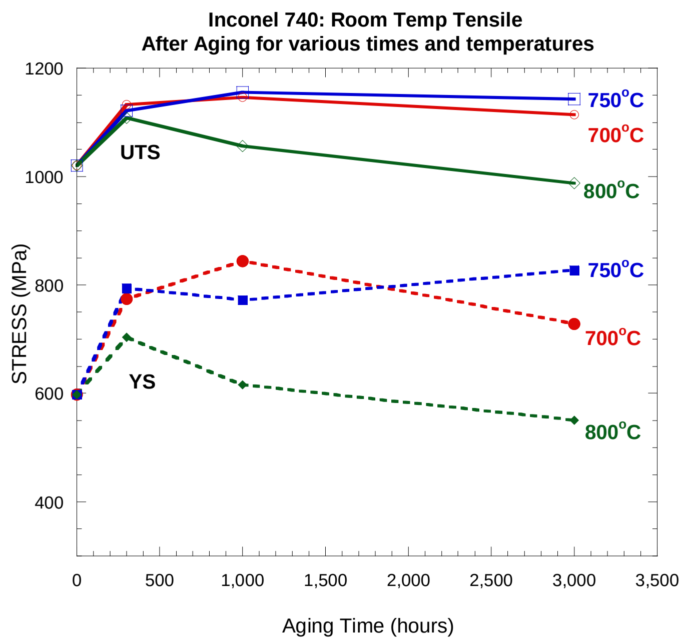
The primary objectives of this subtask are:

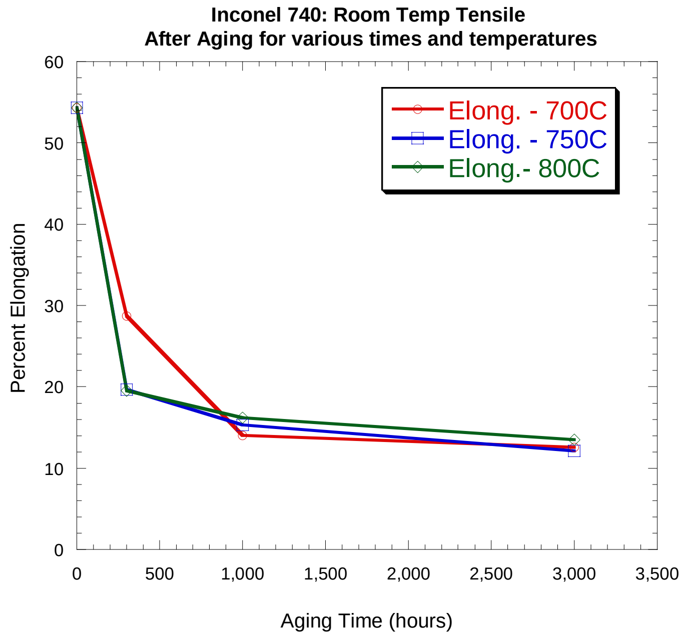
- Identify the microstructural changes that lead to significant changes in the strengthening, weakening, and internal damage characteristics of each material.
- Explore how these changes relate to the exposure conditions of the testing.

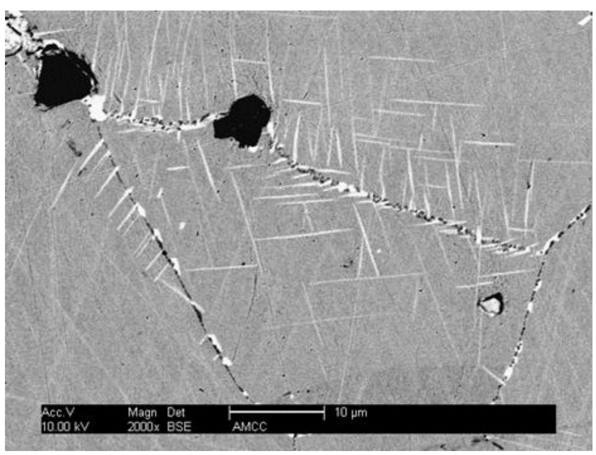
Progress:

The University of Cincinnati (UC) has been tasked with the metallurgical characterization of the USC materials (excluding the SAVE12). The characterization work at the UC includes: microhardness, optical microscopy, scanning electron microscopy (SEM) with elemental analysis by energy dispersive spectroscopy (EDS), and transmission electron microscopy (TEM). Short-term aging is being done on the USC materials at the UC in addition to longer-term aging at ORNL. Creep-tested specimens have also been analyzed. The goal of the aging is to understand the microstructural evolution of the USC materials at temperatures encountered during service in a boiler. The creep-tested specimens will be used to understand differences in microstructural evolution compared to aging without stress and how dislocations interact with precipitates and other microstructural elements.

During this quarter, analyses were performed on creep tested specimens of CCA617 and Super 304H. Aged and tensile tested Inconel 740 specimens were also evaluated. The room temperature tensile properties (UTS/YS/Elong.) for the 740 after aging in air for various times at 700, 750, and 800°C are shown. A significant drop in tensile strength is observed after aging at 800°C for 3,000 hours. Initial BSE SEM evaluation has identified significant amounts of eta phase extending from the grain boundaries as shown below. Further microstructural evaluation is underway. Typically, the formation of eta phase in Ni-based alloys similar to 740, such as Waspalloy, causes a reduction in strength because the eta phase forms at the expense of the gamma prime precipitates (which are the primary strengthening phase). Additionally, eta is not considered a deleterious embrittling phase such as sigma. Therefore, it is very likely that the reduction in tensile strength without a reduction in ductility after aging at 800°C is due to eta phase formation.







SEM BSE Image of Inconel 740 after aging at 800°C for 3,000 hours. Eta phase is observed at the grain boundaries (appear as light/white needle or plate-like phase originating at the grain boundaries and growing at specific angles/planes)

Task 2E: Assessment of Creep-Fatigue Properties

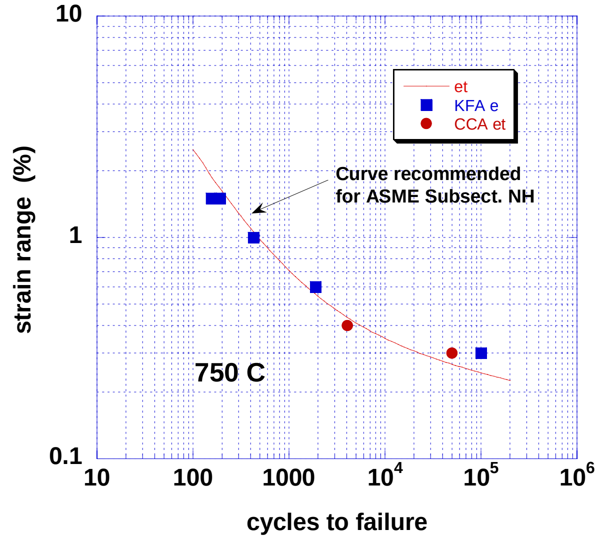
Objective:

The primary objectives of this subtask are:

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

Progress:

Testing on CCA617 began this quarter. The tests to date appear to correlate well with the published fatigue data on standard 617 as shown by the red points in the plot below.



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. The tests include: cross-weldments, parallel weldments, and weld-metal-only tests. Initial results show that the tube weldments (cross-weldment tests were recently completed) are slightly weaker than the plate weldments. A table at the end of the section shows a comparison of the rupture lives for various configurations. Testing also continues on butt-welded tubes of HR6W with 617 filler and 82 filler. Specimens from Super 304H and CCA617 tube weldments have been machined. Dissimilar metal tube welds of CCA617 to Super 304H have also been received. All test results are included in the table below.

Creep-Rupture Testing: Haynes 230 (Tube 5) Cross-Weldments

Spec #	Test #	Stress (MPa)	Temp. (°C)	Base Metal Expected Life	Date Started	Life (hrs)
H230-W01	30311	**350**	**650**	200	6/26/2003	84.9
H230-W02	30290	**300**	**650**	1000	6/3/2003	825.4
H230-W03	30313	**300**	**700**	100	7/1/2003	22.7
H230-W04	30319	**200**	**700**	1500	7/10/2003	207.1
H230-W05	30320	**200**	**750**	100	7/14/2003	30.7
H230-W06	30327	**140**	**750**	2000	7/23/2003	170.6
H230-W07	30328	**200**	**650**	10000	7/24/2003	1550.6
H230-W08	30332	**140**	**700**	15000	8/6/2003	1472
Creep-Rupture Testing: Haynes 230 (Tube 2) Cross-Weldments						
H230-W09	30361	**100**	**800**	2000	9/23/2003	231.6
H230-W10	30365	**80**	**800**	20000	10/1/2003	419.2
H230-W11	30369	**60**	**800**		10/14/2003	7610.5
H230-W12	30370	**100**	**750**	15000	10/14/2003	1117.8

Creep-Rupture Testing: Haynes 230 Weld Metal (Plate 3)

Spec #	Test #	Stress (MPa)	Temp. (°C)	Estimated Life (hrs)	Date Started	Life (hrs)
W3-01	30403	**200**	**650**	1500	1/22/2004	2426.2
W3-02	30454	**140**	**700**	1500	5/13/2004	
W3-03		**100**	**750**	1500		
W3-04*		**100**	**750**	1500		
W3-05		**80**	**800**	1500		`
***Fusion Zone Sample**						

Creep-Ruture Testing:Haynes 230 Cross Weld (Plate 2)

Spec #	Test #	Stress (MPa)	Temp. (°C)	Estimated Life (hrs)	Date Started	Life (hrs)
CW-01	30418	**200**	**650**	1500	3/2/2004	3738.8
CW-02		**140**	**700**	1500		
CW-03		**100**	**750**	1500		
CW-04	30508	**80**	**800**	1500	10/20/2004	

Creep-Rupture Testing:Haynes 230 Parallel Weld (Plate 2)

Spec #	Test #	Stress (MPa)	Temp. (°C)	Estimated Life (hrs)	Date Started	Life (hrs)
PW-01	30419	**200**	**650**	2000	3/2/2004	5462.1
PW-02		**140**	**700**	2000		
PW-03		**100**	**750**	2000		
PW-04	30517	**80**	**800**	2000	11/11/2004	

Creep-Rupture Testing of HR6W Tubing w/617 Welds						
Spec #	**Test #**	**Stress (MPa)**	**Temp. (°C)**	**Estimated Life**	**Date Started**	**Life (hrs)**
617W-01	30459	**175**	**650**		5/24/2004	
617W-02	30460	**120**	**700**		5/24/2004	
617W-03		**85**	**750**			

Creep-Rupture Testing of HR6W Tubing w/82 Welds						
Spec #	**Test #**	**Stress (MPa)**	**Temp. (°C)**	**Estimated Life**	**Date Started**	**Life (hrs)**
82W-01	30465	**175**	**650**		6/9/2004	
82W-02		**120**	**700**			
82W-03		**85**	**750**			

Haynes 230: Rupture Lives for Weldments - Hours (Failure location)						
Stress (MPa)	**Temp. (°C)**	***Base Metal expected***	**Tube Cross-Weldment**	**Thin-Plate Cross-Weldment**	**Weld Metal from Thin Plate**	**Parrallel Thin-Plate Weldment**
200	**650**	10,000	1550.6 (W)	3738.8 (W)	2426.2	5462.1 (Mult. Cracks in Weld)
140	**700**	15,000	1472.0 (W)		2515.8	
100	**750**	15,000	1117.8 (W)			
80	**800**	20,000	419.2 (W)	1152 (in test)		624 (in test)

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:

A series of relaxation tests on the Abe alloy were analyzed vs. manufacturer creep data on SAVE 12 and recently published data by Abe. At lower stress levels (below 100MPa), the relaxation rate for the Abe alloy appears better (lower rate) than creep-rate data on SAVE 12. The relaxation rates measured appear to be very close to the creep rate data on the alloy published by Abe.

Task 2H: Model Validation

Objectives:

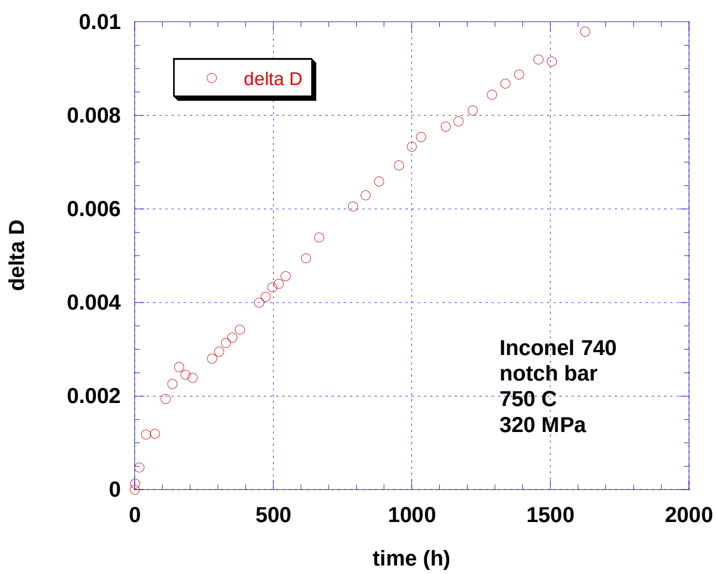
The primary objective of this task is:

- 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, continues on two Haynes 230 bends and one HR6W bend. The test temperature was set at 775°C. It was agreed, through discussions with Task 8, that this temperature would be aggressive enough to produce recrystallization during the tests while keeping the pressures within safety limits. The internal pressure was set to produce rupture in 24,000 hours; based off the current ASME Section I formula for tubes. The tubes were measured using a CMM (Coordinate Measuring Machine) before testing. The tubes were removed after 1,000 hours and after 3,000 hours (total test time) and measured. The specimens are now close to 5,000 hours total test time.

Notched bar testing on the deeply notched 740 specimen continues over 2,000 hours. The diameter change measured in the notch using a specialized diametral extensometer. The plot of this extensometer is shown below.



Pressure-burst specimens, with three wall thicknesses, have been machine from Inconel 740. The tests will be used to examine the multi-axial creep behavior of the 740 and examine the newly proposed ASME wall thickness equations.

Concerns:

The consortium heat of HR6W does not match the strength reported by Sumitomo for other HR6W heats. The result may be improperly characterized effects in the cross-weld data and the U-bend tube tests due to strength less than that of the eventual commercial alloy. Various publications show large discrepancies in the creep strength of Inconel 740 compared to the consortium data. ORNL is currently in contact with Special Metals to understand this issue. A close look at weld strength reduction factors will be required by the consortium and Task 8 as the initial cross-weld data on some alloys shows over an order of magnitude difference in creep life for the weldments compared to the base material.

Plans for Next Quarter:

Work on the third and fourth assessment report will continue. ORNL will continue discussions with Special Metals to resolve issues with the strength of Inconel 740. Further microstructural evaluation of the aged and tensile tested Inconel 740 will continue with emphasis on the formation and growth of eta phase. Cross-weldment testing on CCA617 and Super 304H weldments should begin.

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:

Due to the funding situation, additional testing was not possible during the past quarter. Analysis of the already-generated data at 650°C and 800°C continued during this quarter, as well as comparisons between data generated by BWRC and ORNL. The results of these analyses are presented below:

Descaled Weight Loss

Plots of the descaled weight loss experienced by the alloys tested at 650°C as a function of time as shown in Figures 1-4 **[Figures 1-4 contain information that should not be released]**. As shown in Figures 1 and 2, the ferritic alloys MARB2 and VM12 exhibited, by far, the lowest oxidation rates of the ferritic alloys tested. The austenitic and Ni-based alloys shown in Figures 3 and 4 all displayed oxidation that was less than the ferritic materials, with the Co-containing Ni-based alloys Nimonic 263, CCA 617 and Alloy 740 displaying the lowest oxidation. All of the materials exhibited parabolic or quasi-parabolic oxidation behavior, with the exception of the pre-oxidized MARB2 material which appeared to experience breakaway oxidation between 1,000 and 3,000 hours of exposure.

Figure 5 **[Figure 5 contains information that should not be released]** shows a comparison of the descaled weight loss experienced by alloys tested at 650°C and 800°C for 1,000 hours. This plot indicates that, as expected, the overall oxidation of materials increased with increasing temperature. However, an increase in the steam temperature from 650°C to 800°C did not produce a significant change in the behavior of the test materials relative to one another, at least during a 1,000 hour exposure. At both temperatures, the oxidation resistance of materials with <12% Cr appears to be strongly dependant upon the chromium content. The oxidation resistance of these materials is also influenced by factors other than the chromium content, as evidenced by significantly different oxidation rates being displayed by materials with essentially the same chromium content. The oxidation behavior of materials containing >12% Cr is less dependant upon the chromium content than are materials containing < 12% Cr. This is most likely due to the formation of stable chromium oxides on these materials.

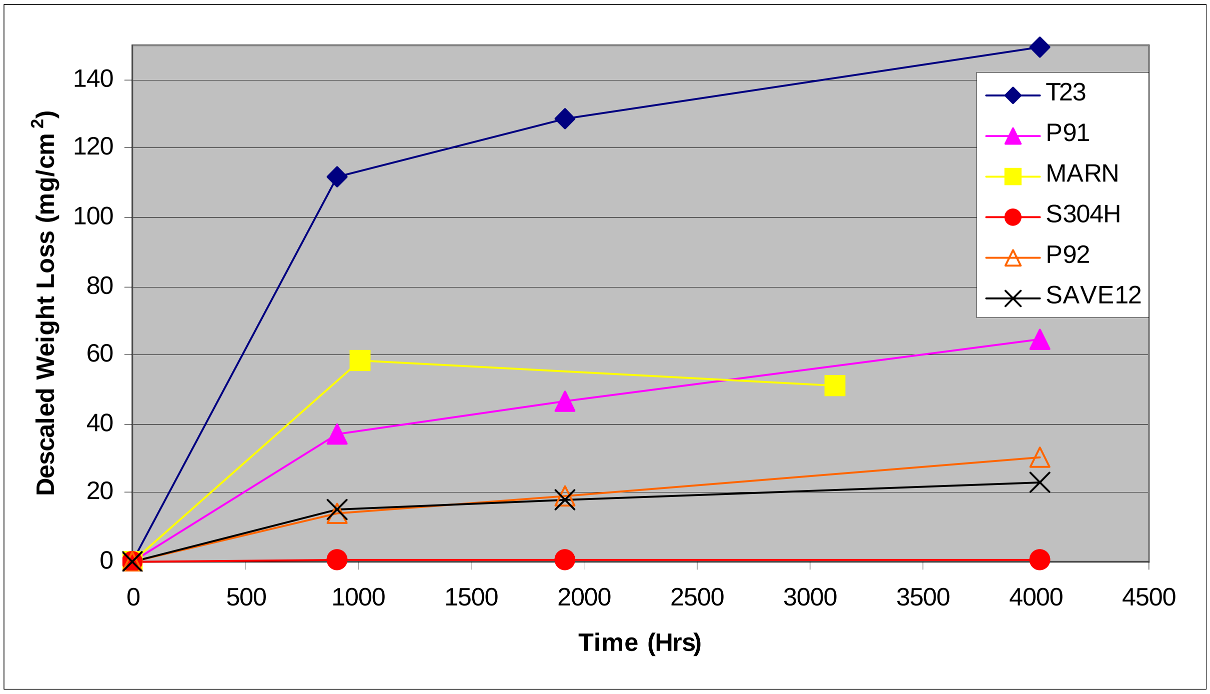


Figure 1. Descaled Weight Loss of Ferritic Materials at 650°C (S304H included as a reference)

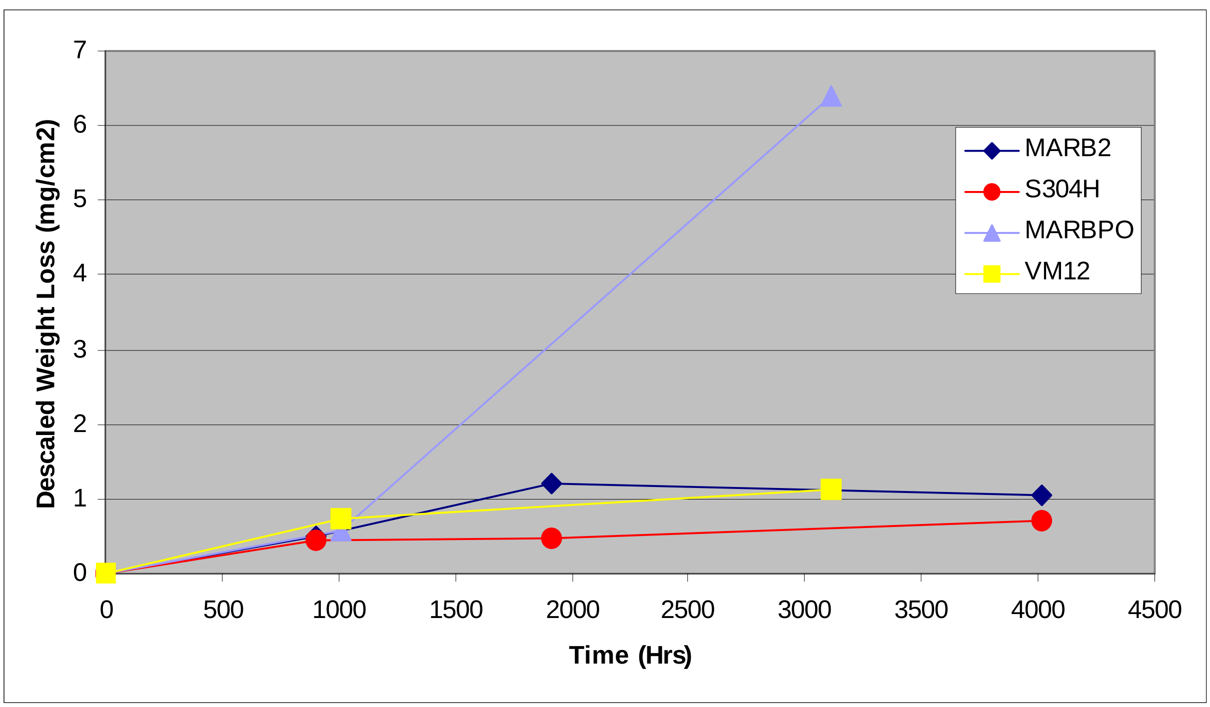


Figure 2. Descaled Weight Loss of Ferritic Materials at 650°C (S304H included as a reference)

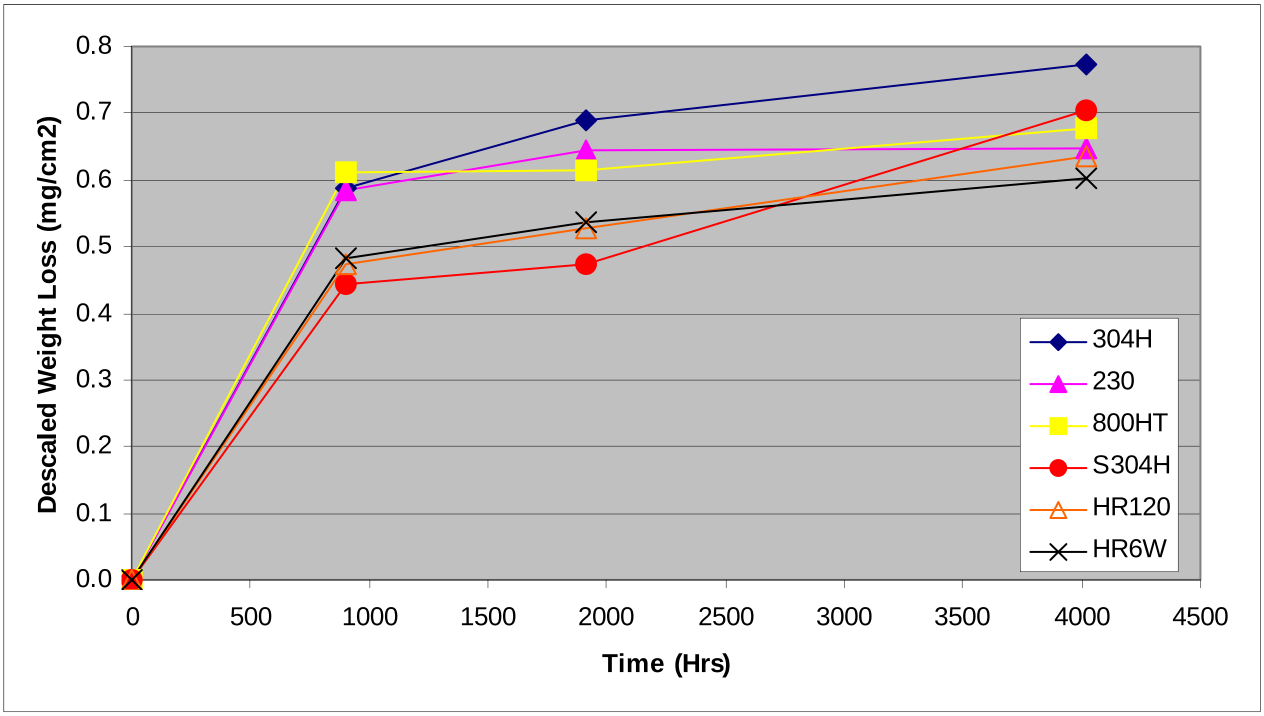


Figure 3. Descaled Weight Loss of Austenitic and Ni-Based Materials at 650°C

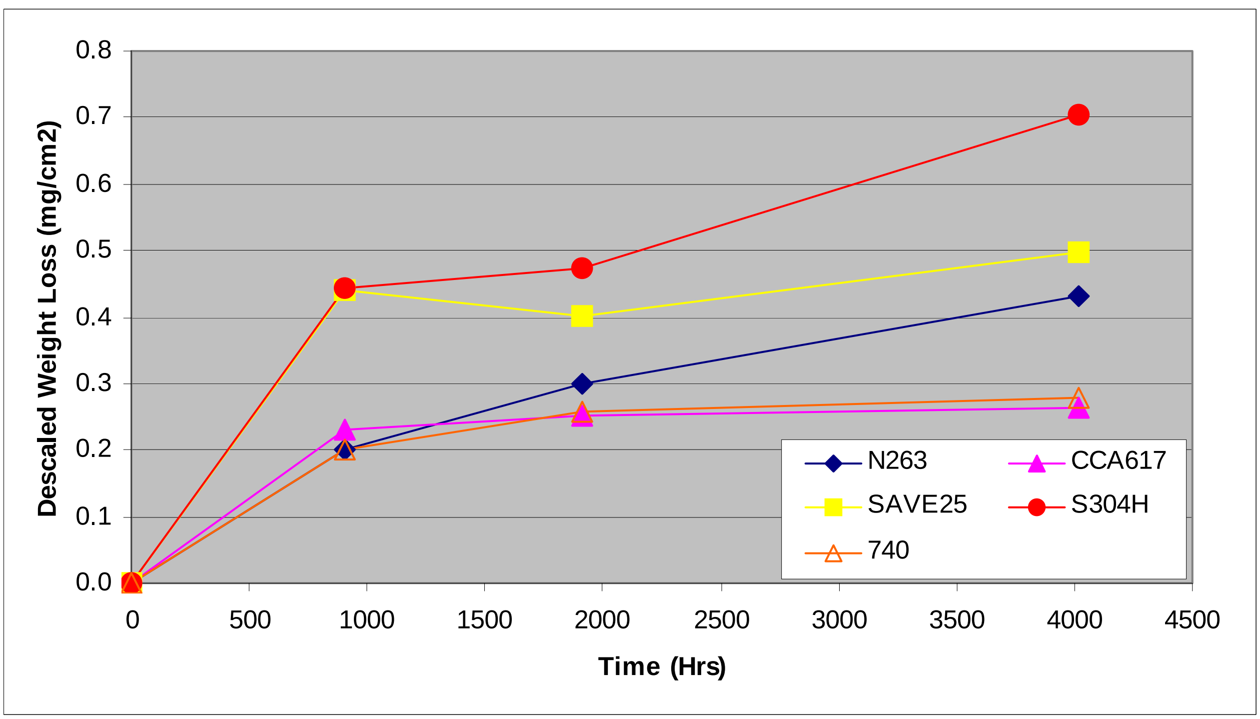


Figure 4. Descaled Weight Loss of Austenitic and Ni-Based Materials at 650°C

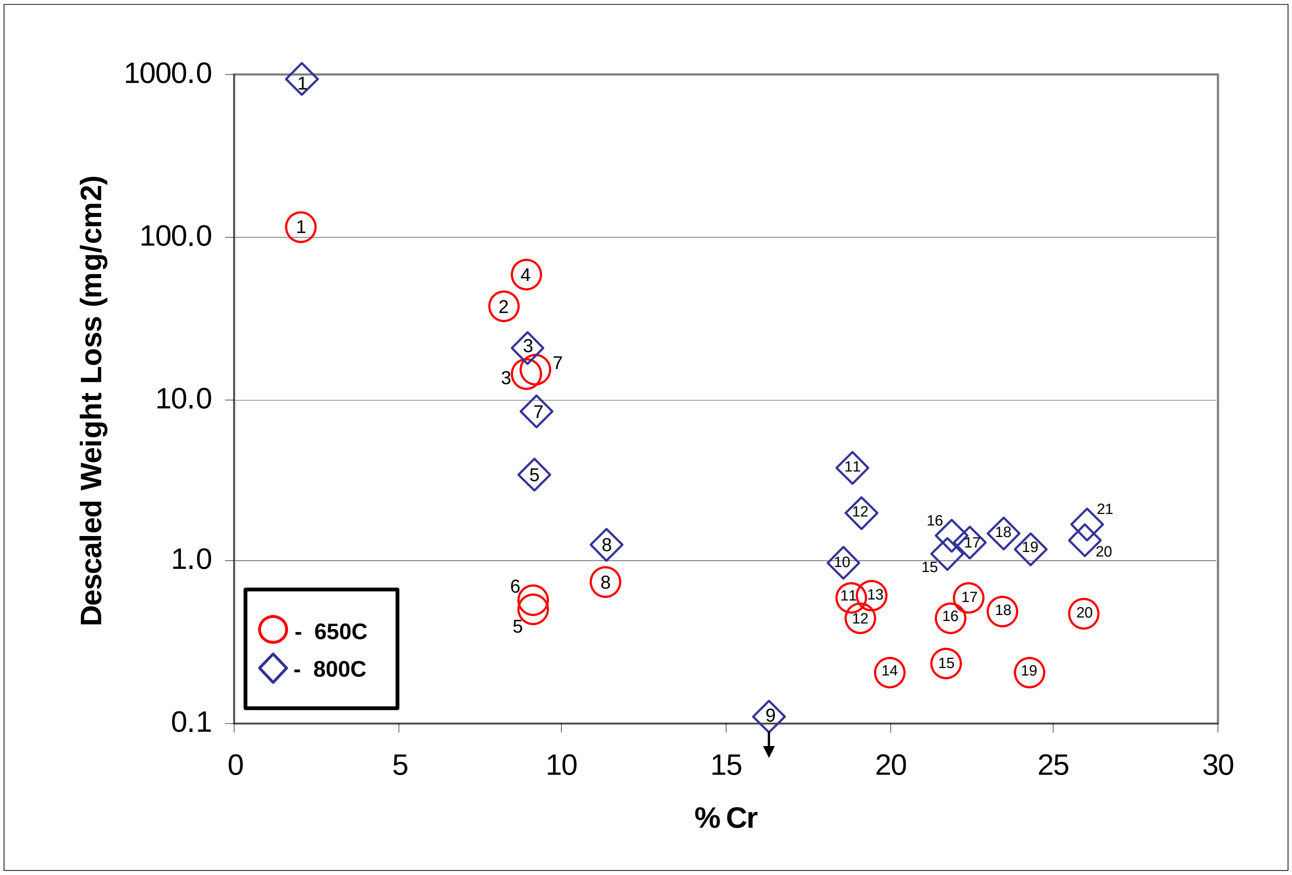


Figure 5. Comparison of Descaled Weight Loss of Materials Tested at 650°C and 800°C

Exfoliation

The weight of exfoliated oxide from each material was calculated using the following procedure:

1) using the measured descaled weight loss, the non-descaled weight gain that would have been realized had no exfoliation occurred was calculated. This calculation was made using the following assumptions: a) for ferritic materials, all weight loss was from Fe atoms, b) for austenitic materials, all weight loss was from metal with a molecular weight of 55.5 g/mole, c) for ferritic materials, the weight gain is due to incorporation of oxygen in the formation of Fe_3O_4, and d) for austenitic materials, the weight gain is due to incorporation of oxygen in the formation of a metal oxide with the composition of M_2O_3.

2) the calculated weight change is then subtracted from the actual measured post-test weight change. Since the weight change represents only the weight of the oxygen which has been incorporated into the oxide, this value is converted to mg of exfoliated oxide per unit area by assuming that the exfoliated oxide from ferritic materials was

Fe_3O_4, and that the exfoliated oxide from austenitic materials was M_2O_3, where M had a molecular weight of 55.5 g/mole.

Figures 6 and 7 **[Figures 6 and 7 contain information that should not be released]** show the measured descaled weight loss and the calculated weight of exfoliated oxide for the materials tested at 650°C for 4,000 hours and at 800°C for 1,000 hours. For materials which displayed negative exfoliation, it can be assumed that the exfoliation is negligible (probably not all of the oxide was removed during descaling). Positive values indicate that these materials did experience exfoliation. The exception to this rule is the P92 and SAVE12 specimens tested at 800°C, where a significant amount of oxide was not removed during descaling due to the formation of huge oxide nodules during the oxidation test. For materials which had descaled weight losses or exfoliated oxide weights that exceeded the scale of the charts in Figures 6 and 7, the values are provided above or below the corresponding bars.

The results in Figures 6 and 7 suggest that all of the ferritic material experienced significant exfoliation at 650°C except for MARB2 (Abe) and VM12. At 800°C, the MARB2 (Abe) alloy is showing signs of exfoliation, while the oxide on VM12 does not appear to be exfoliating. None of the austenitic or Ni-based materials displayed significant exfoliation at 650°C, but at 800°C, 347HFG, 304H and possibly SAVE25 are showing evidence of exfoliation.

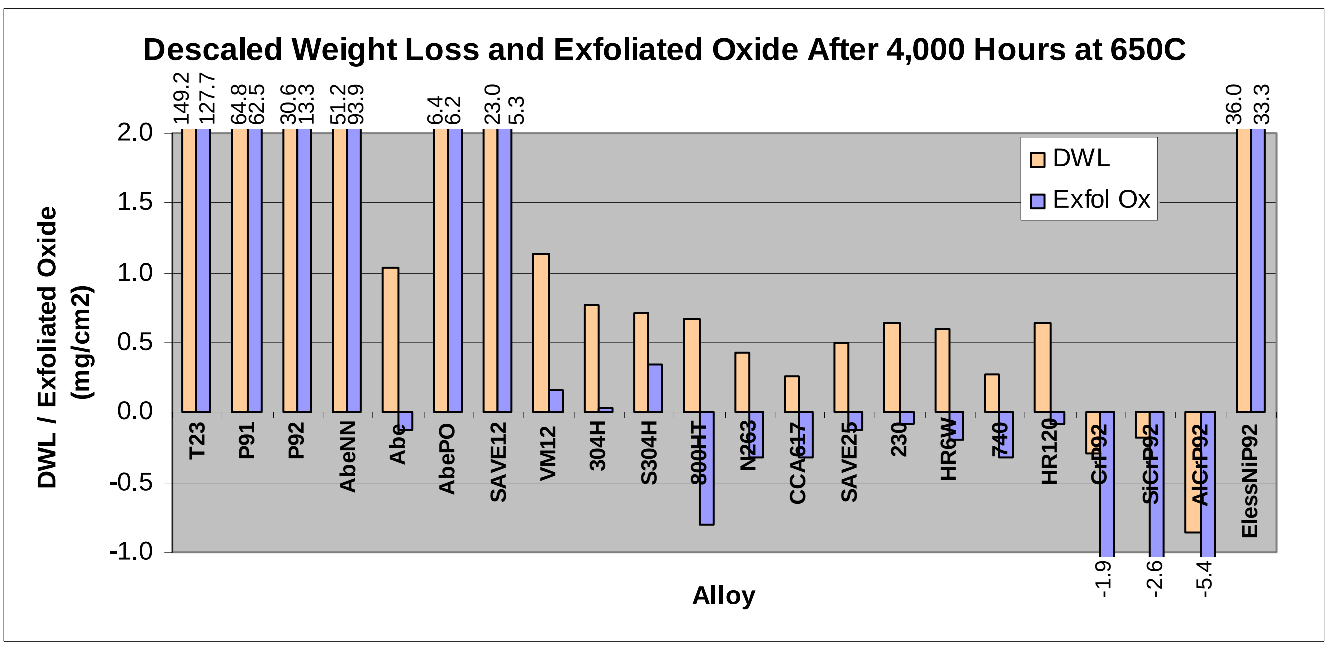


Figure 6. Descaled Weight Loss and Calculated Weight of Exfoliated Oxide of Materials Tested at 650°C for 4,000 Hours

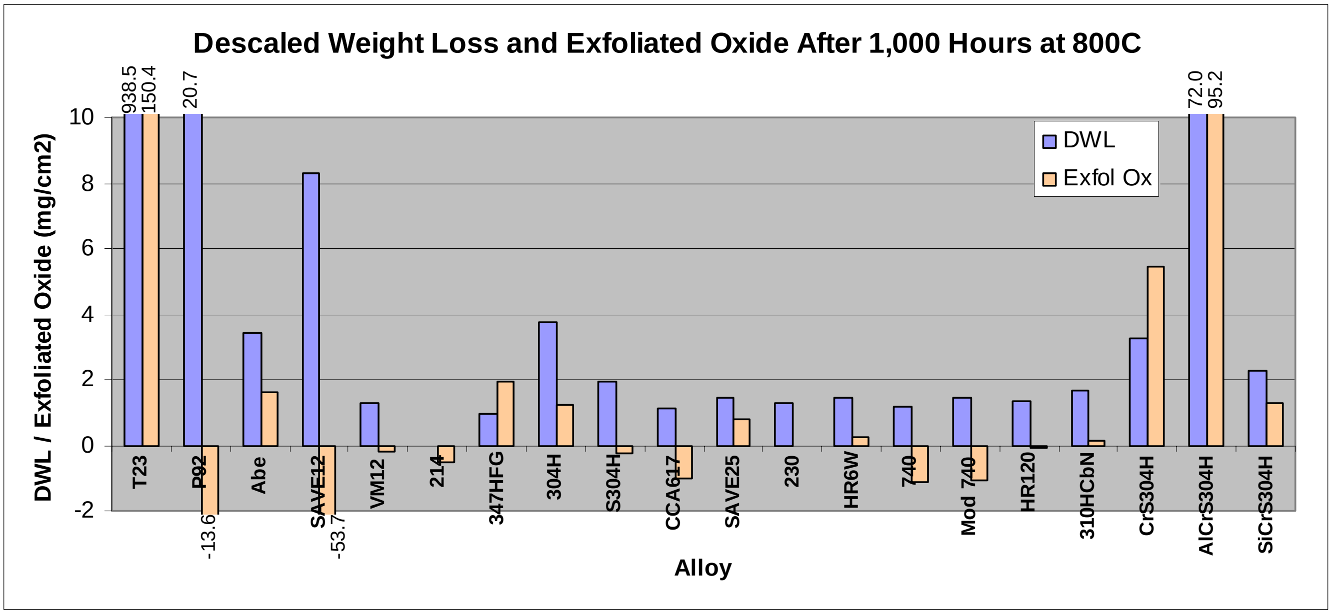


Figure 7. **Descaled Weight Loss and Calculated Weight of Exfoliated Oxide of Materials Tested at 800°C for 1,000 Hours**

Comparison of BWRC and ORNL Steam Oxidation Test Results

BWRC and ORNL are performing complimentary steam oxidation tests on potential USC materials. Table 1 provides a general comparison of the test programs being conducted at these two locations

TABLE 1
Comparison of BWRC and ORNL Steam Oxidation test Conditions

Condition	BWRC	ORNL
Temperature and Time	650°C tests completed for up to 4,000 hours 800°C test completed for 1,000 hours	700°C tests completed for up to 4,000 hours 800°C test completed for up to 4,000 hours 650°C tests in progress
Environment	Oxygenated Treatment Water (pH = 8-8.5 ; 100-300 ppb O_2)	Deaerated Deionized Water
Pressure	Atmospheric Pressure	250 psig
Evaluation Criteria	Primarily based on descaled weight loss	Based on weight change and cross sectional thickness change

Assuming parabolic oxidation kinetics, the steam oxidation rate constants calculated from data generated by BWRC and ORNL on common materials are presented in the plots shown in Figure 8 **[Figure 8 contains information that should not be released].**

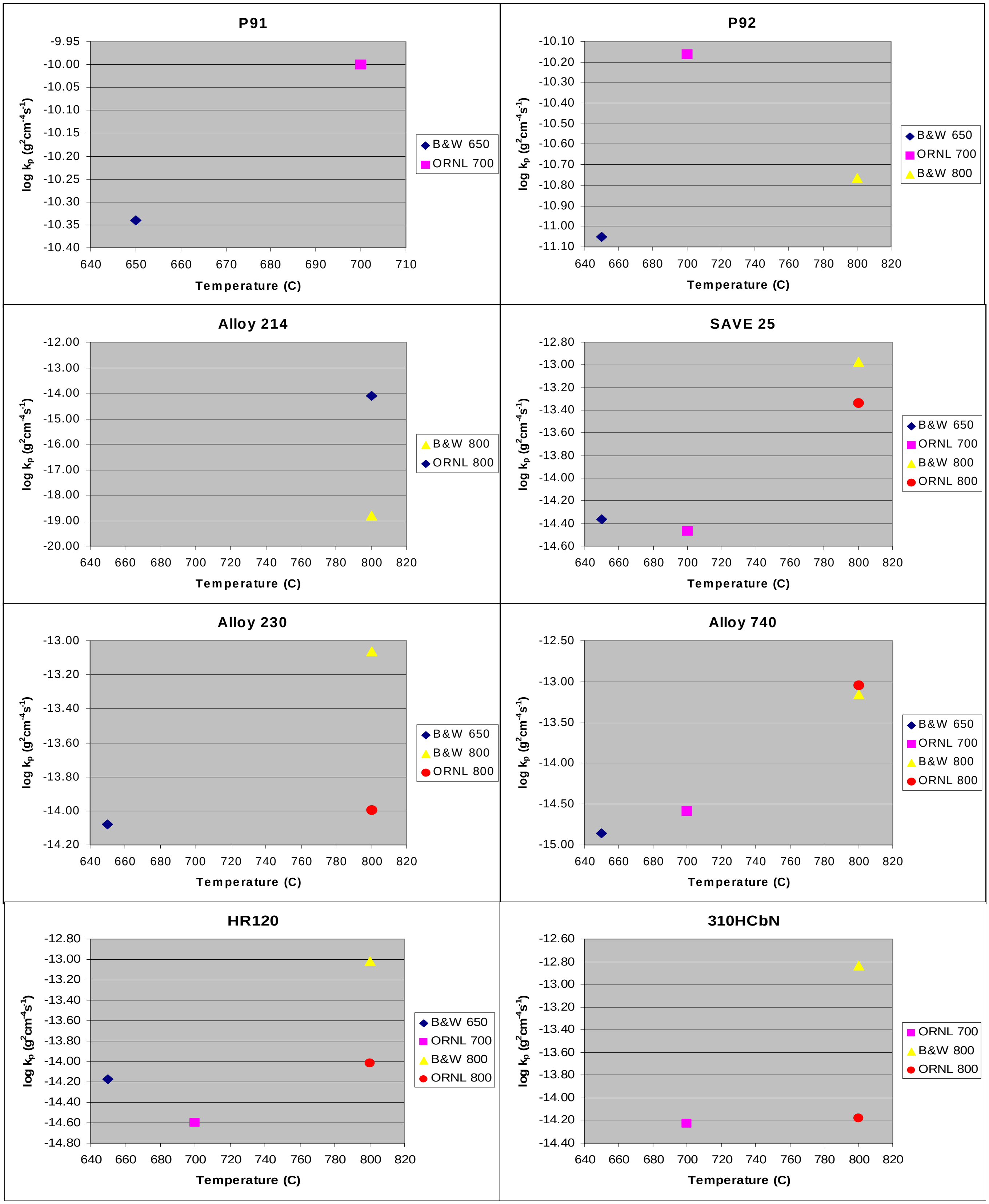


Figure 8. Steam Oxidation Rate Constants Calculated from BWRC (1,000 Hour) and ORNL Data

A compilation of the BWRC and ORNL data is displayed in Figure 9 **[Figure 9 contains information that should not be released]**. This plot indicates that, within the scatter of the data, the BWRC and ORNL results are in relatively good agreement. No systematic differences in the results from the two labs are observed, which is significant since the two labs use different evaluation criteria.

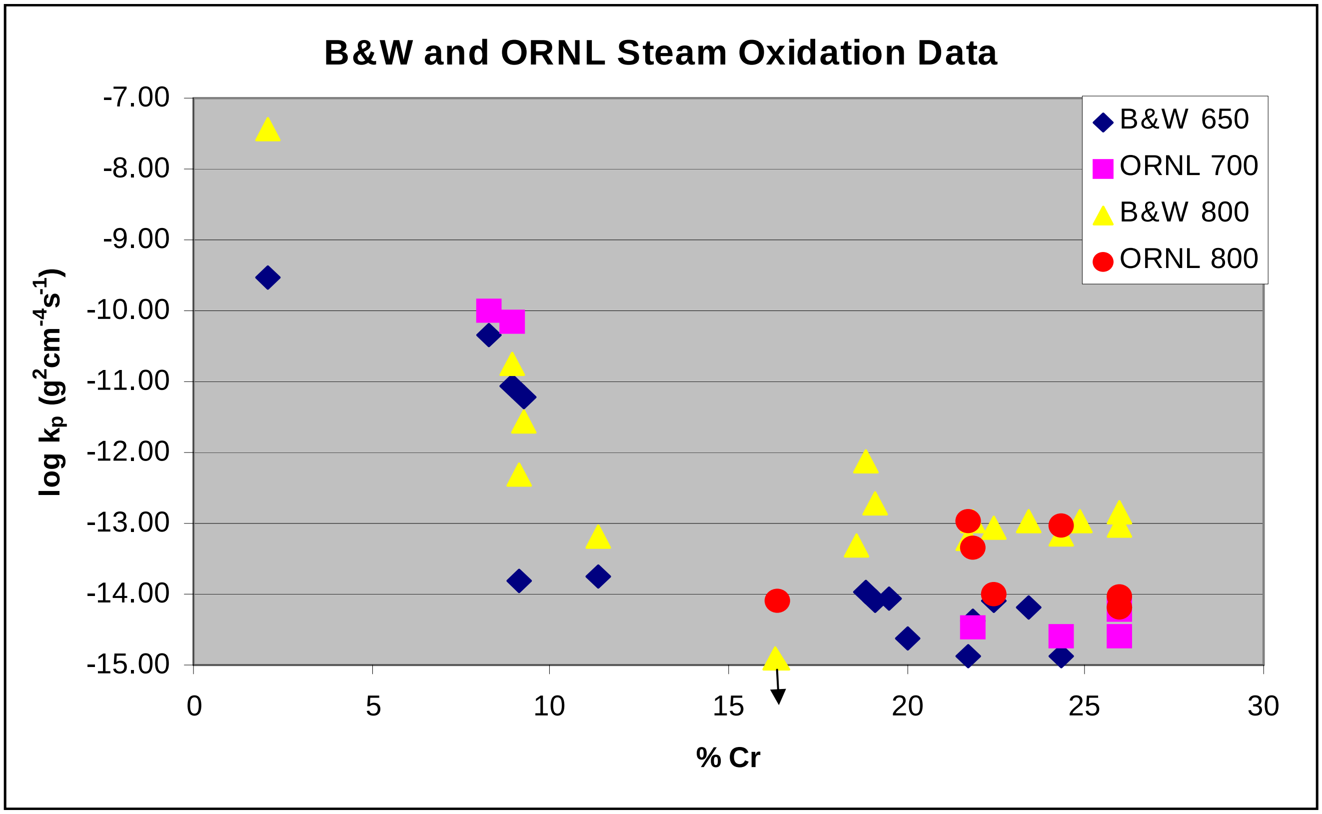


Figure 9. Compilation of BWRC and ORNL Steam Oxidation Results

Sufficient data for the calculation of activation energies (Q) exist for only three materials tested by both BWRC and ORNL (SAVE 25, Alloy 740 and HR120). The results of these calculations are presented in Table 2 **[Table 2 contains information that should not be released]**. Activation energies were calculated from the BWRC calculated weight change data as well as from the actual measured weight change data. The BWRC calculated activation energies for SAVE 25 and Alloy 740 were between 50 and 60% of the activation energies calculated from the ORNL data; however, the activation energies calculated for HR120 from BWRC and ORNL data were almost identical.

TABLE 2
Comparison of Activation Energies (Q) Calculated from BWRC and ORNL Data

Material	Q (kJ/mole)		
	BWRC		ORNL
	From Calculated Wt. Change	From Measured Wt. Change	From Measured Wt. Change
SAVE25	127	107	225
Alloy 740	186	195	308
HR120	106	119	117

The data that has been obtained thus far suggest that the differences in test environment and pressure between the BWRC and ORNL tests have not produced significant or consistent differences in the oxidation behavior of the materials that have been evaluated. A more accurate comparison will become available as tests are performed for longer times and at different temperatures.

Concerns

Due to funding uncertainties and current facility unavailability, the start of the next exposure at 800°C will not be started until the 2nd quarter of GFY05.

Activities Next Quarter

Preparations will be made for the second exposure at 800°C. Specimens from new materials such as NF709, 347W, shot peened 347HFG and SUPER304H, and Nimonic 263 Filler Metal will be prepared, cleaned, measured, weighed and attached to the test rack prior to the second exposure. Assuming that funding is available, the second exposure at 800°C (1,000 hours) should begin during the next quarter

Task 3B Coating Tests

Background:

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

Experimental:

The descaled weight loss and exfoliated oxide weight reported in Figures 6 and 7 suggest that the only coating that suffered exfoliation at 650°C was the electroless Ni, and that all coatings suffered exfoliation at 800°C. While it is true that the post-test appearance of the materials indicated that the electroless Ni coating exfoliated badly at 650°C and the AlCrS304H coating did not perform well at 800°C, descaling of coated specimens tends to be imprecise. When evaluating coatings, the physical appearance of the coatings (as has been reported in previous Quarterly Reports) should always be considered along with any descaled weight loss measurements.

Concerns:

None.

Activities Next Quarter:

Prepare for next 800°C exposure.

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:

Initial activation energy calculations based on 1,000 hour results at 650°C and 800°C were presented previously. Additional progress will be made as test results become available.

Concerns:

None.

Activities Next Quarter:

None.

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 October and November, 2004.

A technical paper entitled “An Evaluation of the Steamside Oxidation of Candidate USC Materials at 650°C and 800°C” by J. M. Sarver and J. M. Tanzosh was presented at the 4th International Conference on Advances in Materials Technology for Fossil Power Plants, October 25-28, 2004, Hilton Head, SC. The paper corresponding to this presentation was finalized and submitted for publication.

The Steering Committee Meeting for the USC project was attended in December in Columbus, Ohio.

A document containing the highlights from USC Task 3 for 2004 was prepared and submitted to EPRI.

Concerns:

None.

Activities Next Quarter:

Monthly status reports will be written for January and February. The Quarterly report for the October - December, 2004 timeframe will be prepared.

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:

None.

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:

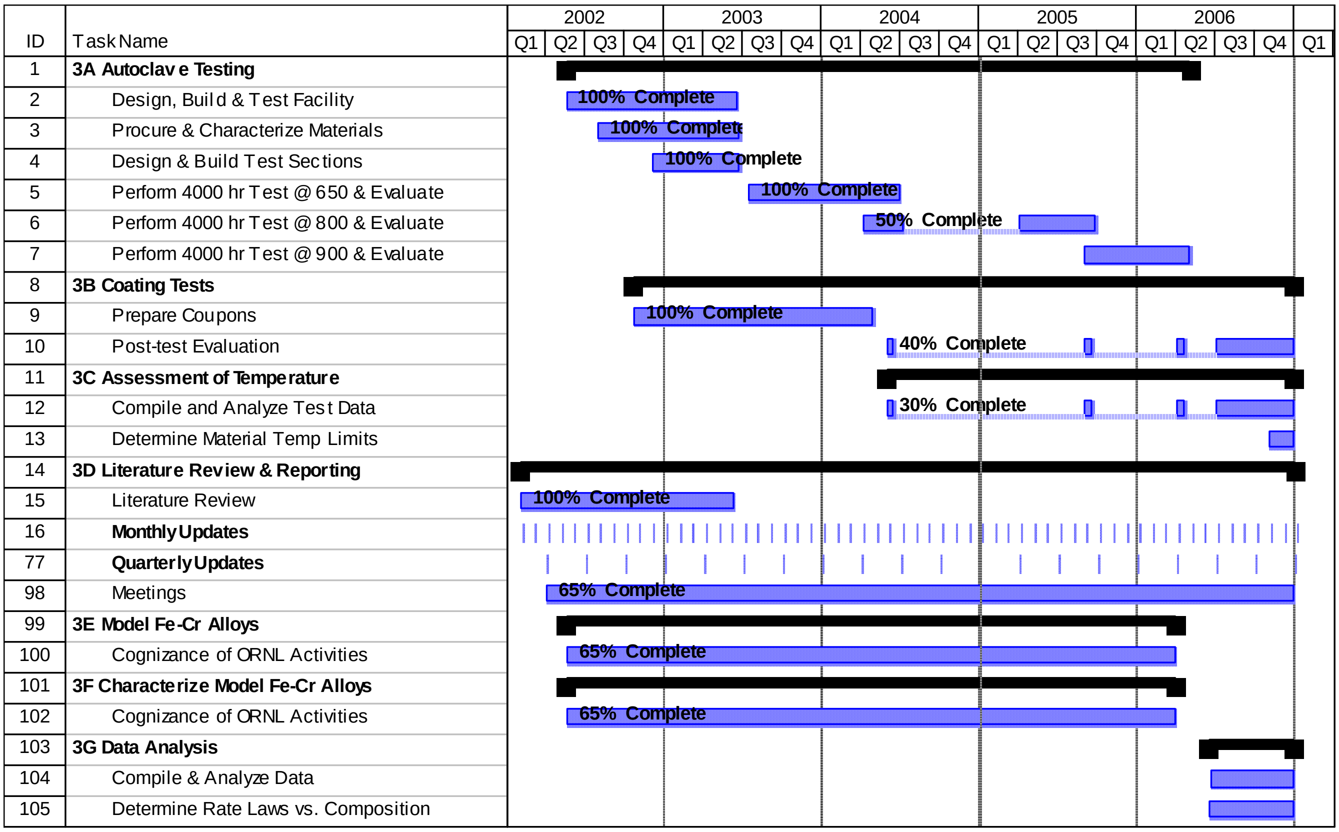
None.

Activities Next Quarter:

None.

Milestone Chart

Dates are listed in GFY



Task 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

Objectives:

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:

The 1000-hour exposure for the third series of laboratory testing was completed. The test temperatures were 1100°F for waterwall conditions and 1300°F for superheater/reheater conditions. (Note: The deposit and flue gas compositions, representing eastern, midwestern, and western fuels, used in the tests were reported in the January – March Quarterly report.) This completes testing for three of the five temperatures for superheater/reheater conditions and for all three temperatures for waterwall testing. The fourth series of testing for superheater/reheater conditions, which is being performed at 1400°F, also commenced. At the end of the quarter, 900 hours of testing in this series was completed.

The post-test analysis of the 1300°F superheater/reheater and the 1100°F waterwall specimens was started. Preliminary wastage results in 1000 hours are shown in Figures 1 and 2, respectively. [Note: The microscopic examination of the specimens for carburization has not been completed.] Since protective coatings may be necessary to mitigate OD wall loss caused by corrosion from the environment, the performance of the weld overlays, laser clad, and diffusion coatings in the laboratory tests is an important issue. Figures 3 through 5 illustrate the surface condition of the coatings being tested after the 1000 hour exposure at 1300°F. [Note: The surface of the samples that were tested under Midwestern conditions, which are the most aggressive, are shown.]

In the laboratory tests performed at 1500°F, specimens containing higher Mo contents experienced greater attack, particularly under Midwestern conditions. To determine if the same behavior occurred at 1400°F, control samples of CCA617 (9Mo) and 740 (0.5Mo) were examined after 600 hours of exposure. While both samples displayed subsurface attack as shown in Figure 6, they did not exhibit the significant corrosion that was evident at 1500°F.

Photomacrographs of the cleaned post-test superheater/reheater specimens of selected alloys were taken to illustrate the effect of temperature and deposit/gas conditions on the macroscopic nature of the corrosion morphology. The photomacrographs, which are shown in Figures 7 through 9 for 740, CCA617, and HR3C, respectively, provide a thumbnail illustration of the alloy performance over the range of test conditions. [Note: It is anticipated that a similar macro-photographic summary will be prepared at the end of the laboratory testing for each alloy at all test conditions.]

With regard to the superheater/reheater testing that has been completed to date, the following general comments can be made::

- As expected, specimens tested under Midwestern and Eastern conditions exhibited more wastage than those tested under Western conditions.
- For wrought alloys, the wastage decreased as the chromium level increased. In the absence of the Mo effect (in the 1500°F specimens), the wastage tended to level off for alloys in the 22-27 Cr range.
- Specimens tested at 1200° and 1300°F displayed more surface attack, whereas specimens tested at 1500°F exhibited more subsurface penetration.
- At 1500°F under Midwestern conditions, the Mo-containing alloys experienced more attack than the alloys without Mo; the higher the Mo, the greater the wastage.
- Of the weld overlays, 72 (typically 42Cr) and 52 (typically 28Cr) performed better than 622 (typically 21Cr) at all temperatures, with 72 performing better than 52. At 1200° and 1300°F, the 72 and 52 were better than the wrought alloys in the 22-27 Cr range.
- With regard to the diffusion coatings (on Super 304H), the FeCr and SiCr coatings performed better than the AlCr coating, which exhibited extensive subsurface attack. The FeCr and SiCr coatings were comparable to the weld overlays, but because they are thinner will be breached sooner.

The surface appearance of the wrought specimens tested at 1100°F for 1000 hours under waterwall conditions is shown in Figure 10. Similar to the comment made for superheater/reheater materials, protective coatings may be necessary to mitigate OD wall loss due to corrosion on waterwall tubing. Figures 11 through 13 illustrate the surface condition of the weld overlay, laser-clad, and diffusion-coated samples after 1000 hours at 1100°F.

General comments regarding the waterwall testing completed to date are:

- Similar to the superheater/reheater testing, specimens tested under Midwestern and Eastern conditions exhibited more wastage than those tested under Western conditions.

- The difference in the amount of wastage between the Midwestern/Eastern and Western conditions was greater at 850° and 975°F than at 1100°F.

- The Abe and Save12 alloys displayed higher wastage than the P92 and HCM12A alloys, respectively, at all three test temperatures.

- The 622, 52, and 72 weld overlays and 50/50 laser-clad displayed significant improvement in corrosion resistance compared to the wrought alloys at all test temperatures. The 622 overlay began to exhibit more attack at 1100°F compared to 52 and 72.

- With regard to the diffusion coatings (on T92), they also exhibited significantly improvred corrosion resistance compared to the wrought alloys. The chromized coating displayed the best performance followed by the SiCr and the AlCr coatings. As in the superheater/reheater tests, the AlCr coating exhibited the most subsurface attack

Concerns:

No concerns at this time.

Plans for Next Quarter:

- Finish 1000-hour cycle at 1400°F for superheater/reheater samples.

- Start fifth 1000-hour test cycle for superheater/reheater conditions, which will be performed at 1600^{o}F..

- Continue with microscopic evaluation of samples exposed in the previous 1000 hour test cycles.

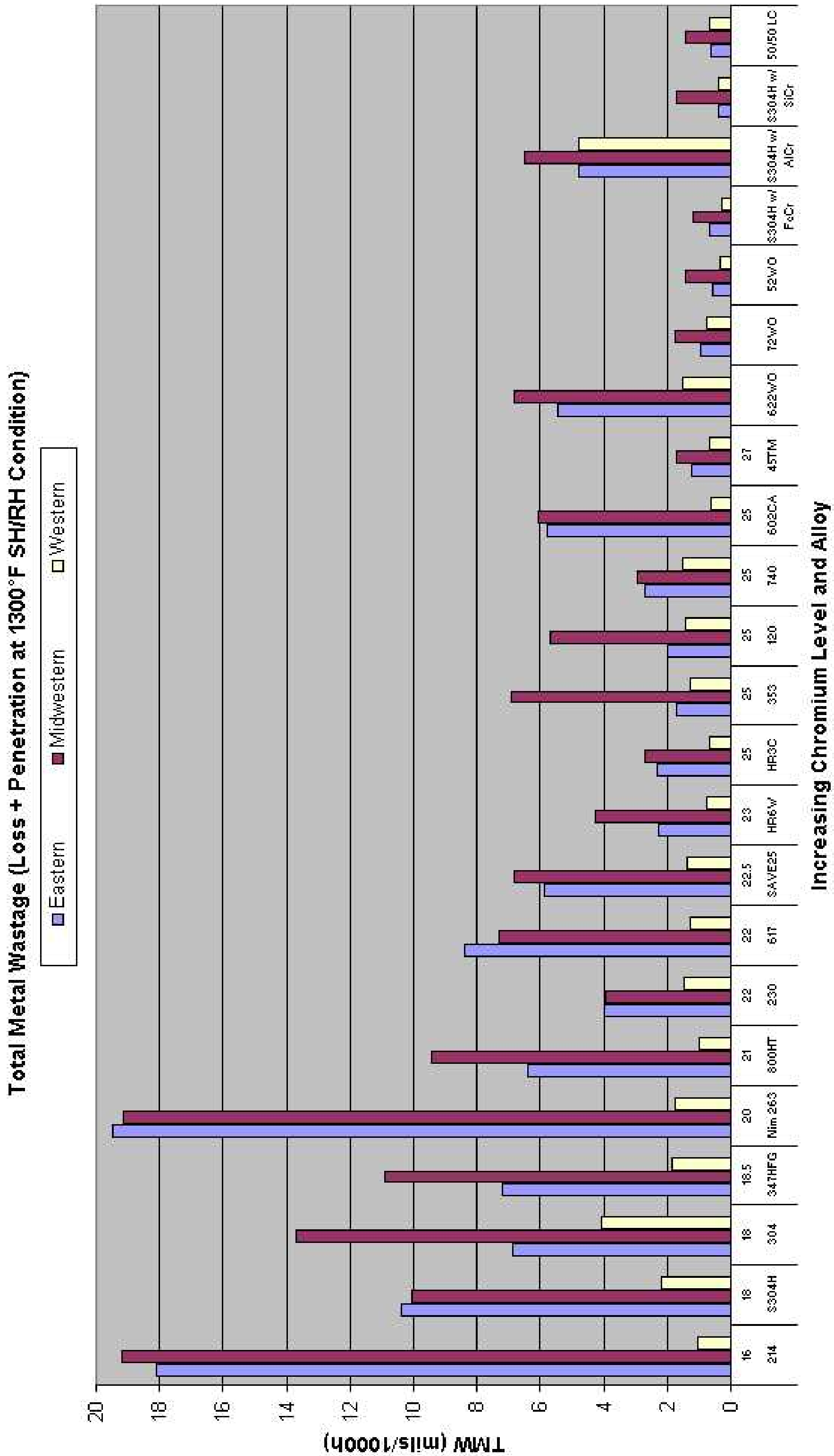


Figure 1: Figure 1: Preliminary results of the Total Metal Wastage (wall loss plus subsurface penetration) of the 1300°F superheater/reheater specimens in 1000 hours are shown.

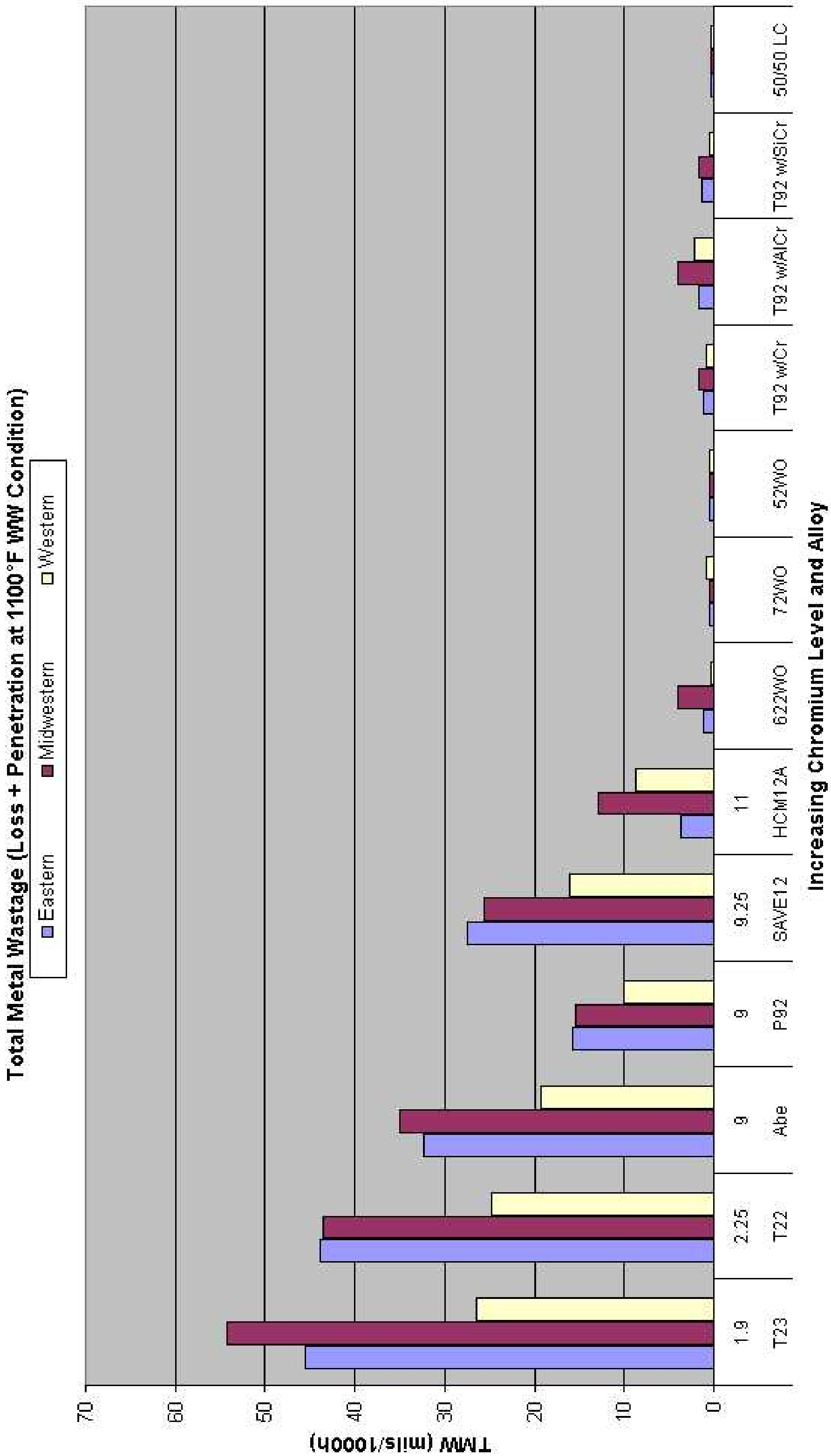


Figure 2: Preliminary results of the Total Metal Wastage of the 1100°F waterwall specimens in 1000 hours are presented.

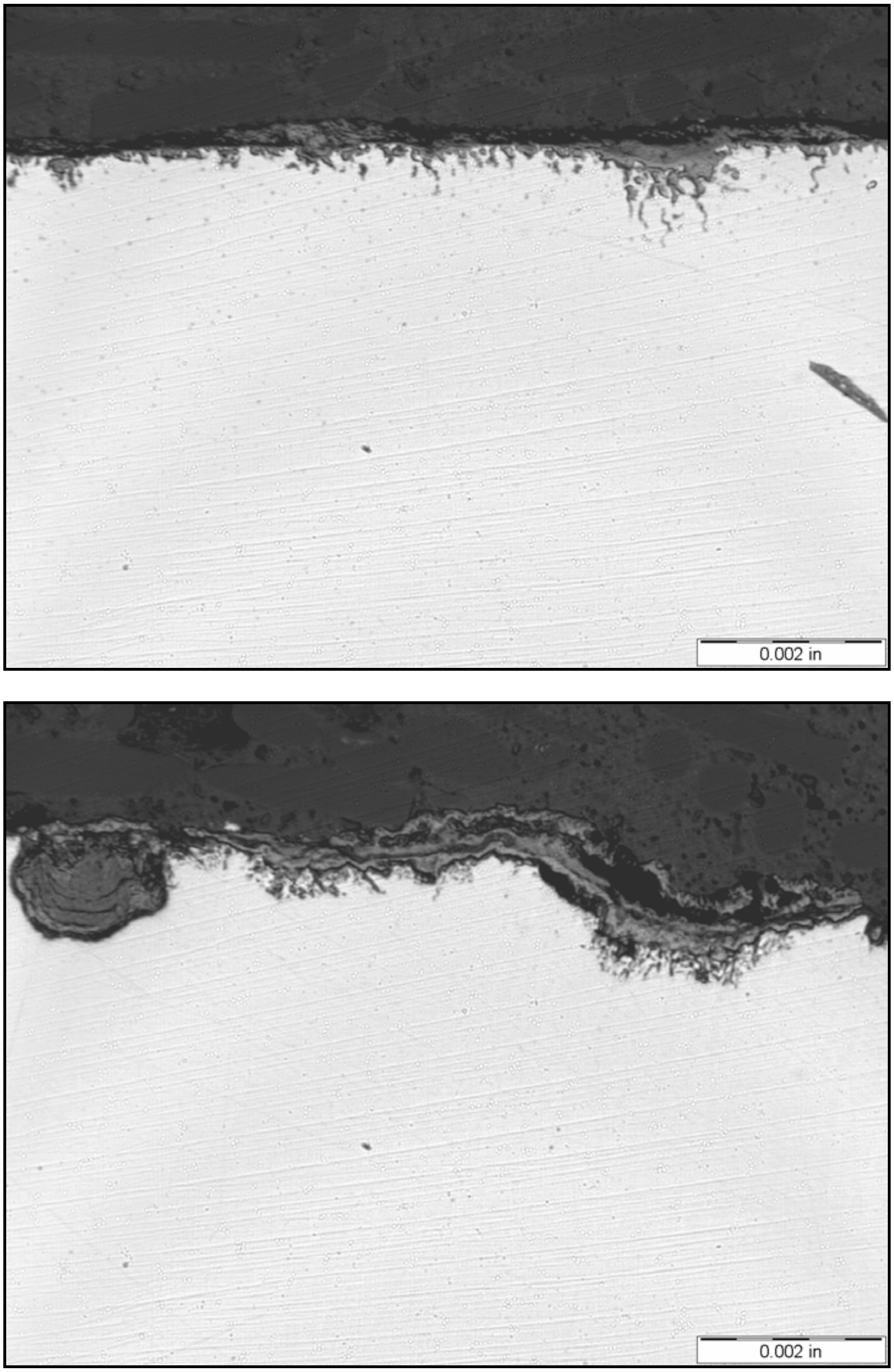
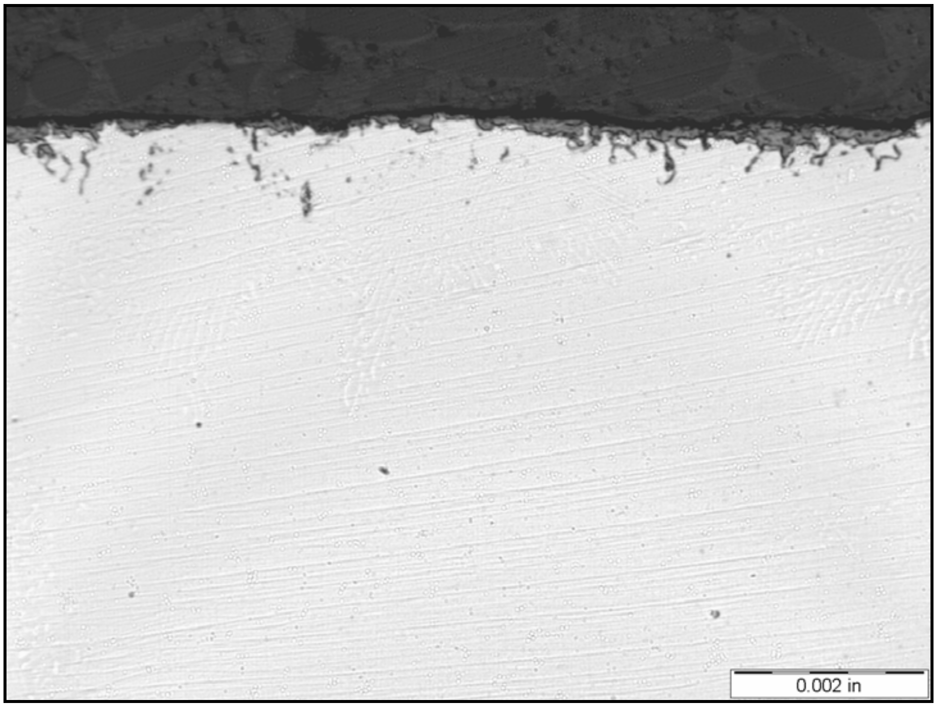


Figure 3: The morphology of subsurface attack in the 52 (top) and 622 (bottom) weld overlays tested under Midwestern conditions at 1300°F for 1000 hours is illustrated.



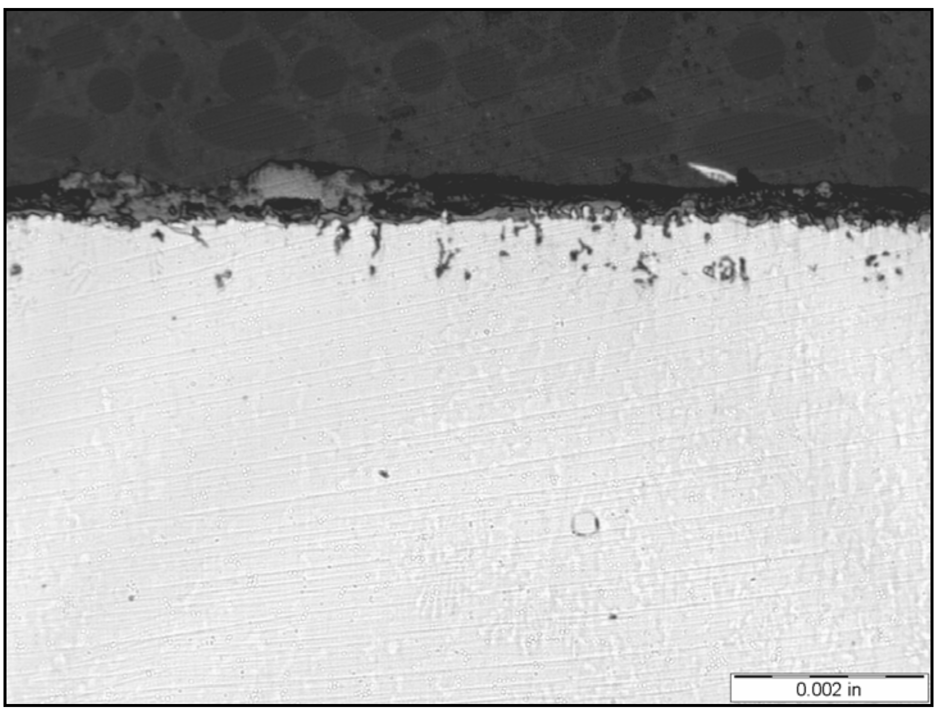


Figure 4: The microscopic appearance of the subsurface attack in the 72 weld overlay (top) and 50/50 laser-clad (bottom) specimens tested under Midwestern conditions at 1300°F for 1000 hours is displayed.

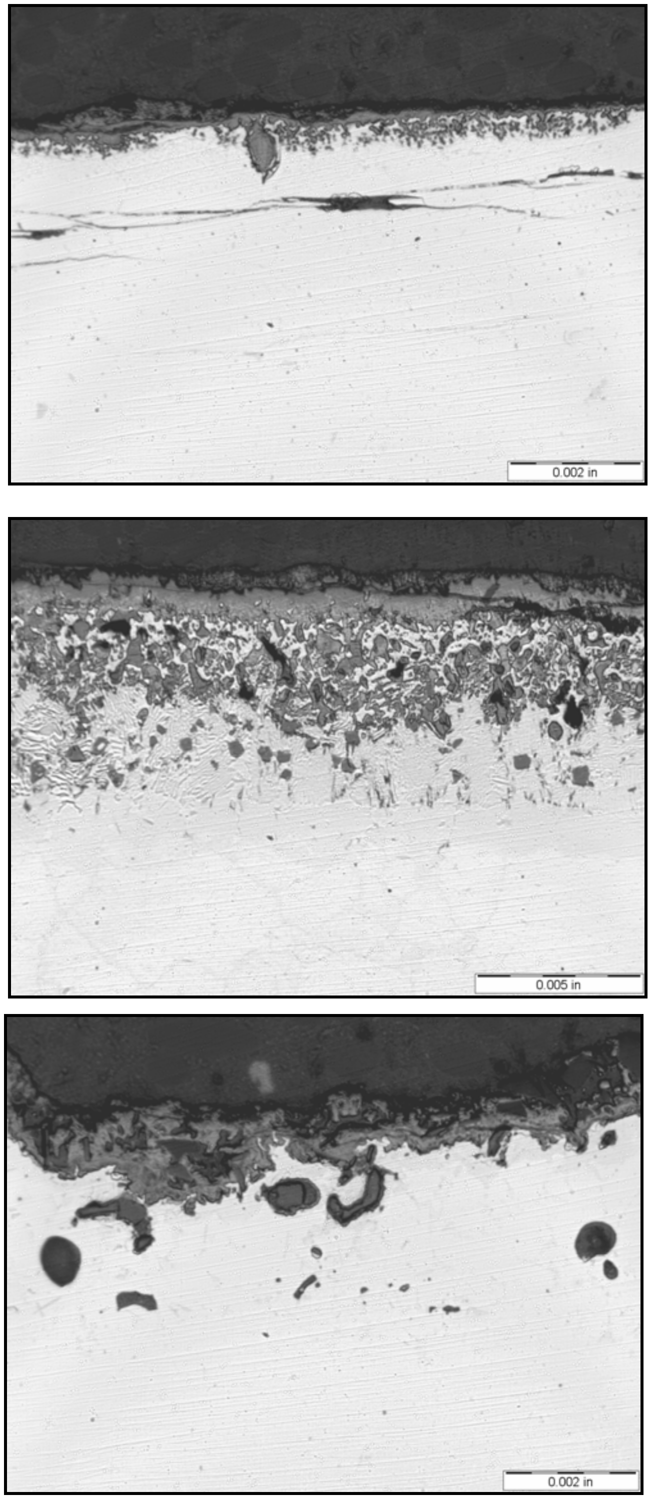


Figure 5:The surface condition of the FeCr (top), AlCr (middle), and SiCr (bottom) diffusion coatings is shown after testing under Midwestern conditions at 1300°F for 1000 hours. The AlCr coating suffered extensive subsurface attack

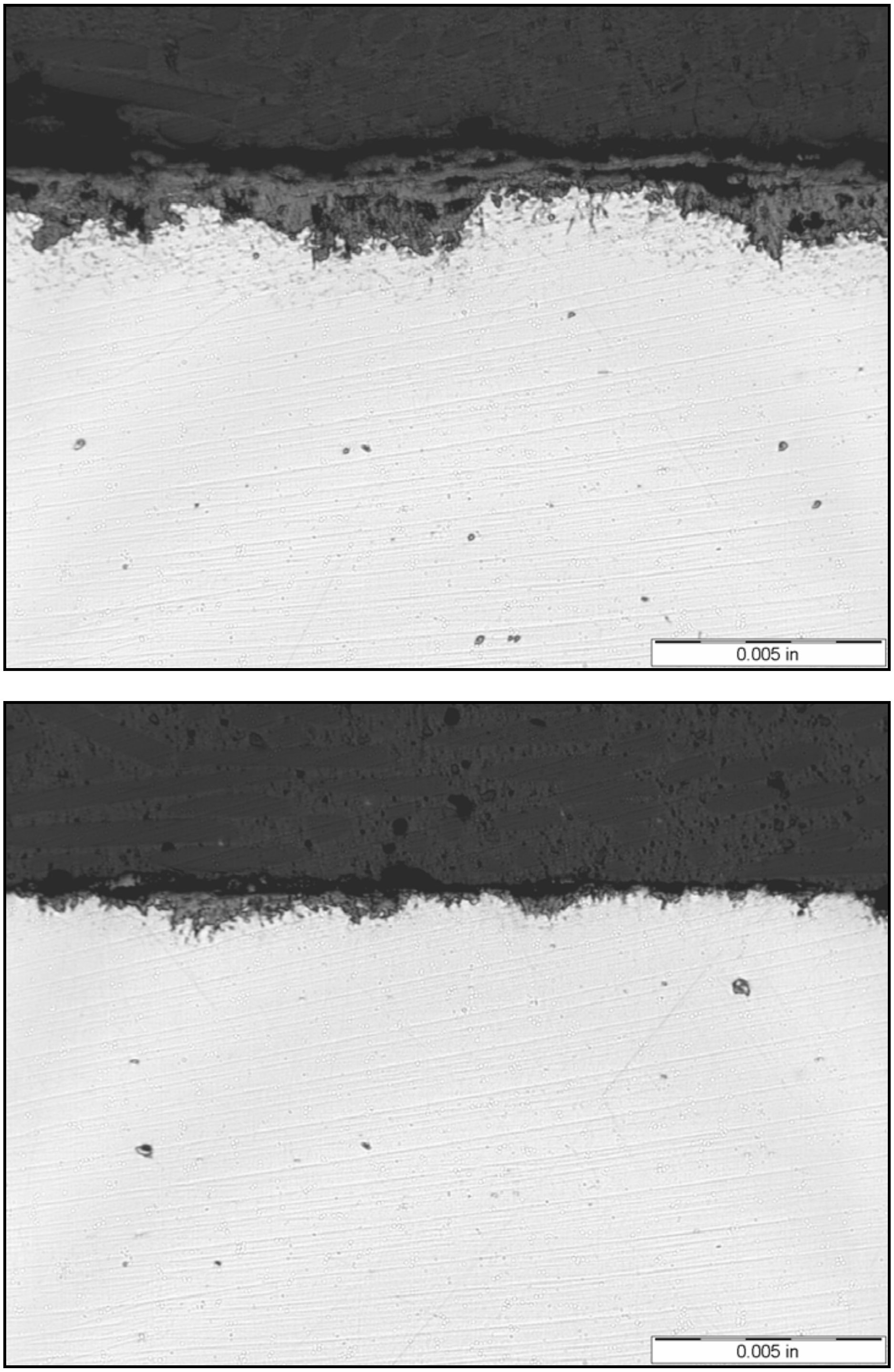


Figure 6: The morphology of subsurface attack in the CCA617 (top) and 740 (bottom) specimens tested under Midwestern conditions at 1400°F for 600 hours is depicted. Neither specimen exhibited the significant corrosion that was evident at 1500°F under Midwestern conditions

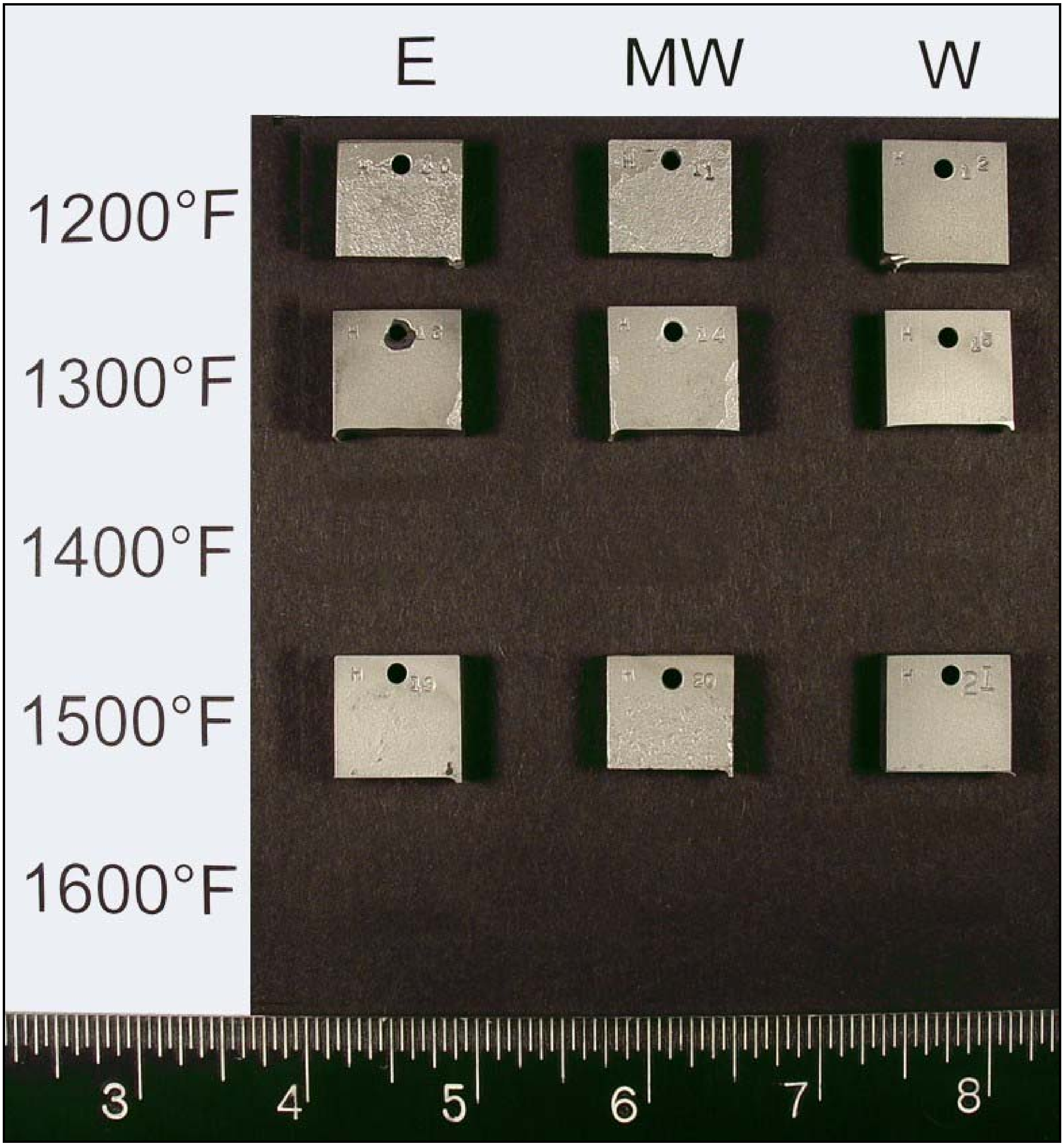


Figure 7: The post-test, cleaned appearance of the 740 superheater/reheater specimens tested to date illustrate the macroscopic nature of attack experienced under the various test conditions.

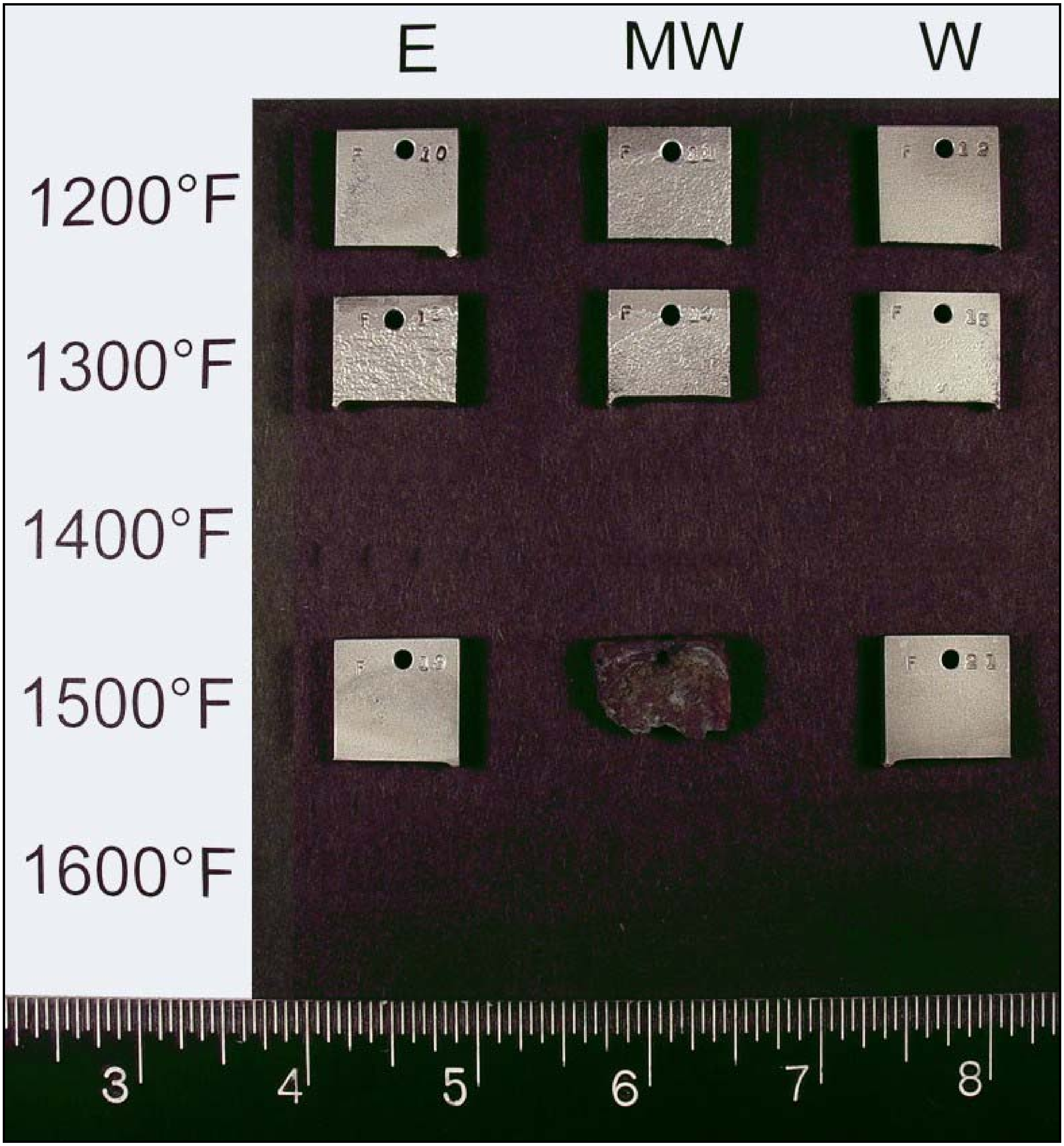


Figure 8: The post-test, cleaned appearance of the CCA617 superheater/reheater specimens tested to date illustrate the macroscopic nature of attack experienced under the various test conditions. The specimen tested at 1500°F under Midwestern conditions suffered catastrophic attack.

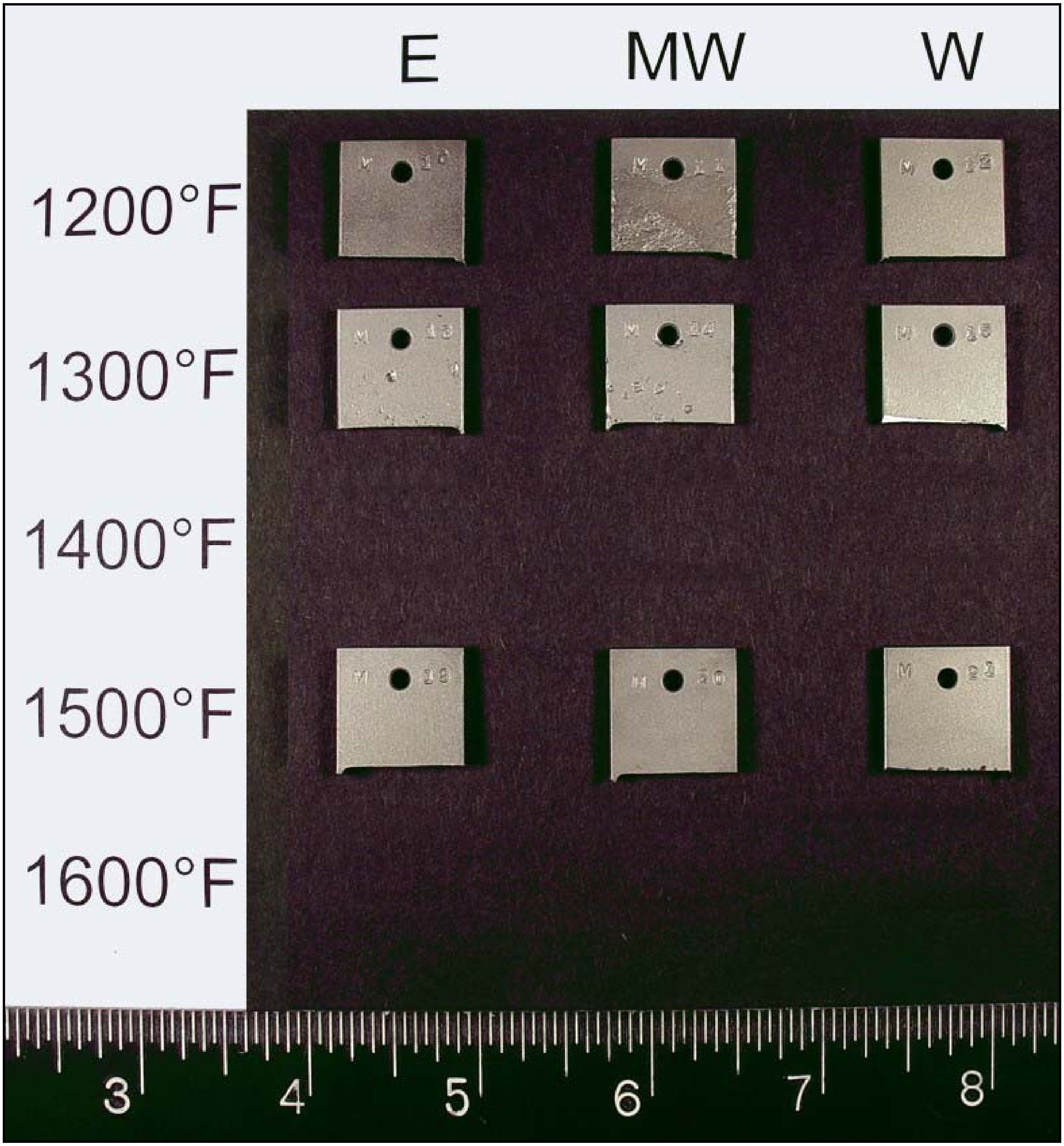


Figure 9: The post-test, cleaned appearance of the HR3C superheater/reheater specimens tested to date illustrate the macroscopic nature of attack experienced under the various test conditions.

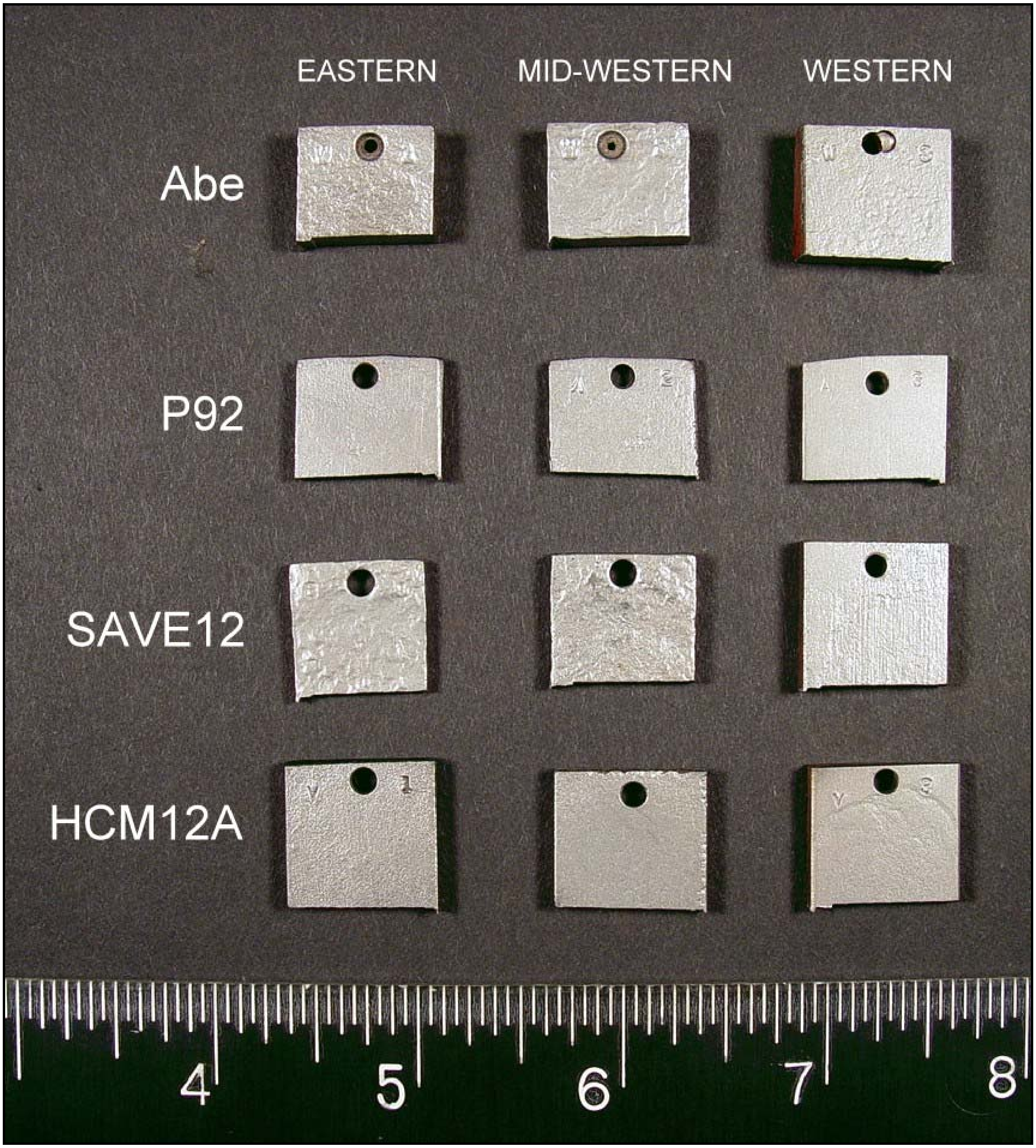


Figure 10: The post-test, cleaned appearance of the wrought waterwall specimens tested at 1100°F illustrate the macroscopic nature of attack under the Eastern, Midwestern, and Western conditions.

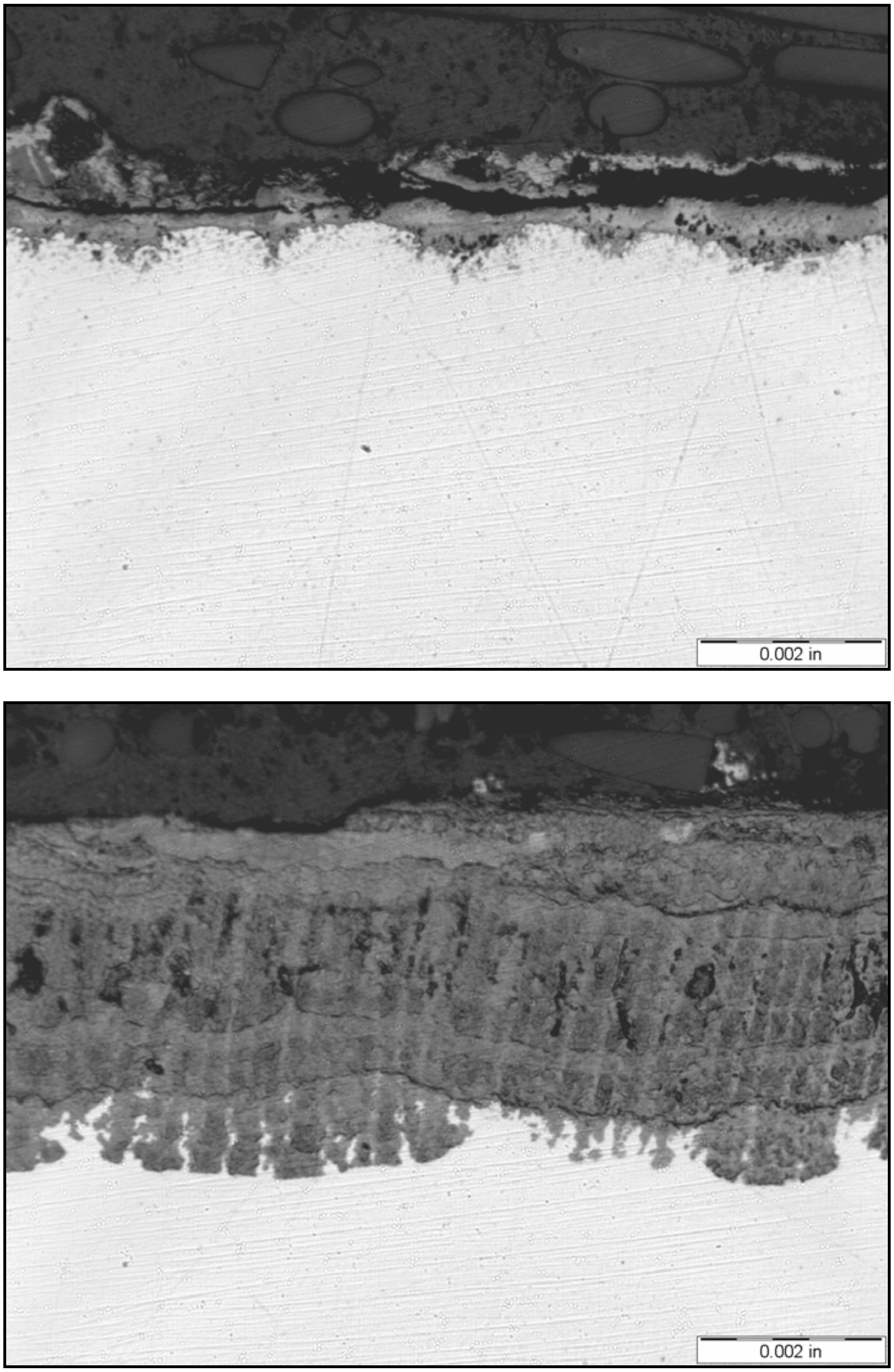


Figure 11: The morphology of the subsurface attack in the 52 (top) and 622 (bottom) weld overlays tested under Midwestern waterwall conditions at 1100°F for 1000 hours is displayed.

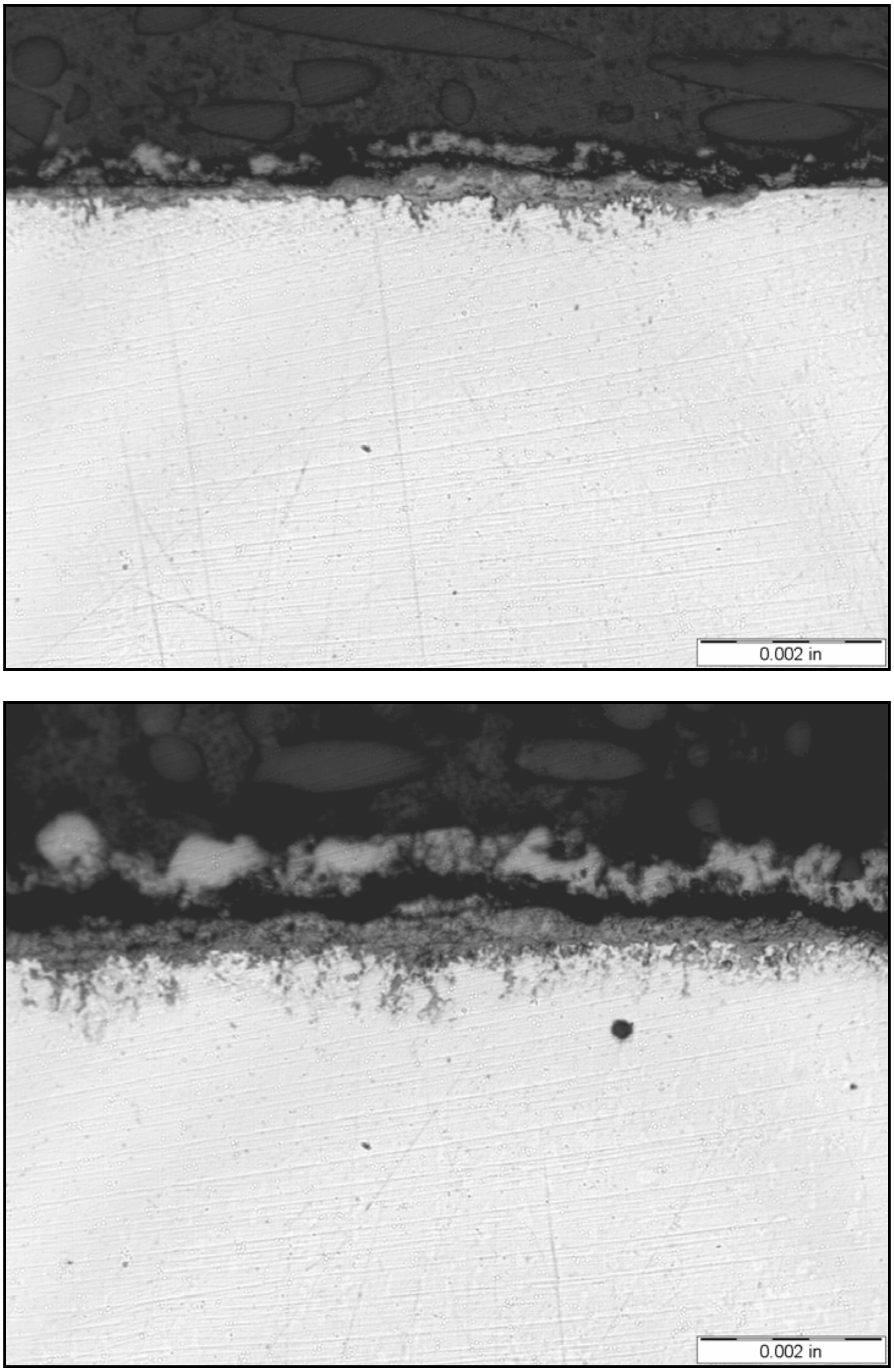


Figure 12: Subsurface attack in the 72 weld overlay (top) and 50/50 laser-clad specimens tested under Midwestern waterwall conditions at 1100°F for 1000 hours is illustrated.

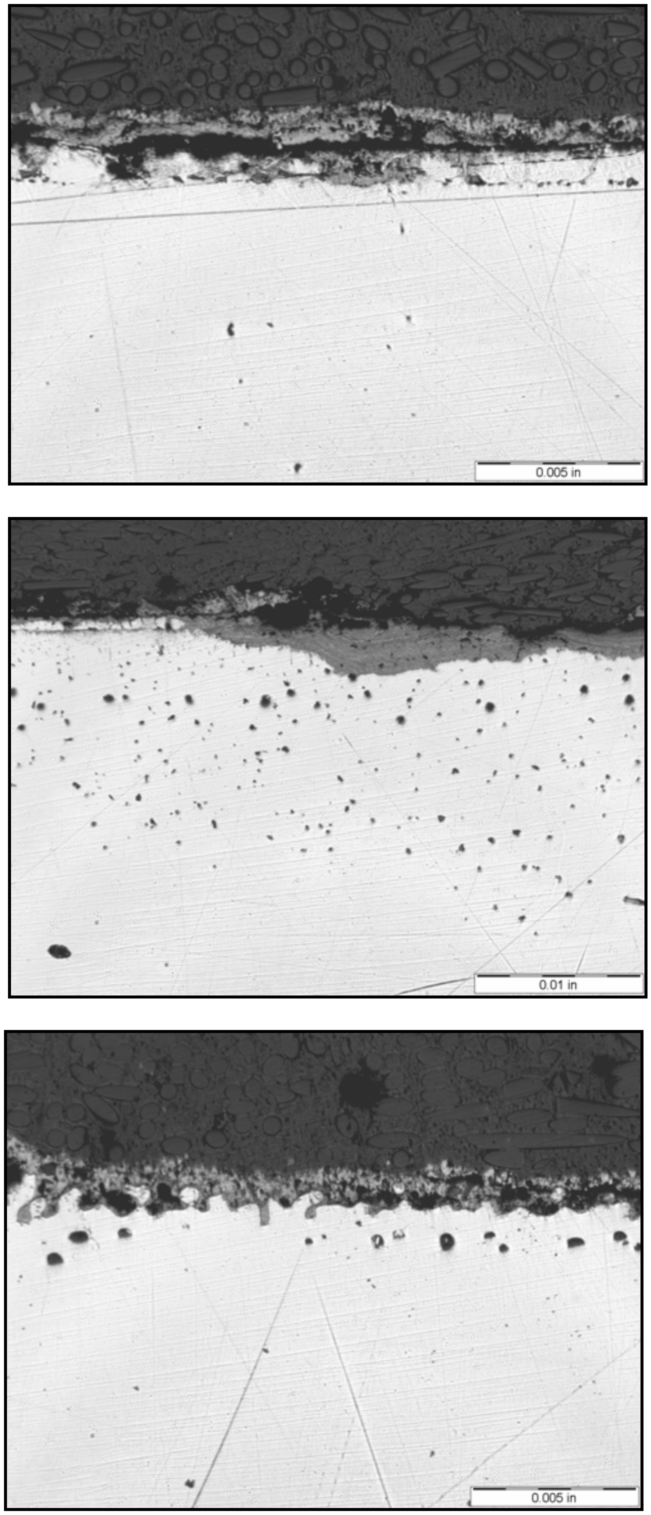


Figure 13: The surface appearance of the FeCr (top), AlCr (middle), and SiCr (bottom) diffusion coatings tested under Midwestern waterwall conditions at 1100°F for 1000 hours is shown. As in the superheater/reheater tests, the AlCr coating performed poorly relative to the FeCr and SiCr coatings.

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 first four probe retraction mechanisms, as shown in Figure 14, has been completed. Development of the related data acquisition, instrumentation and control systems have continued. These retraction mechanisms will be installed at two coal-fired plants. The two plants that were selected for the initial installations were Cinergy Gibson Generating Station (Indiana) and Xcel Energy Pawnee Station (Colorado). Gibson is firing a high-sulfur Farmersburg coal, while Pawnee is firing a low-sulfur PRB (e.g., Eagle Butte) coal.

- Design modifications were implemented, resulting in a more unique probe design, for each site, to prevent possible premature failures. New materials and equipment have been incorporated into the probe designs. Foster Wheeler is working closely with the host utility personnel to coordinate installation activities in order to minimize the overall schedule impact of any delays related to revised probe material selection.

- The re-design of the corrosion probe and support core, incorporating the overlay and coated samples has been completed. Fuel differences at each host site have been accounted for in the re-design effort.

- Progress on Task 4B was presented at the December 2004 steering committee meeting. Feedback from the committee members has been incorporated into our ongoing efforts.

Concerns:

- We cannot begin construction and deployment of the corrosion probes for the third host site until incremental DOE funding for FY 2005 is released.

Plans for Next Quarter:

- Assemble the machined specimen and core pieces for the first four probes.

- Instrument the corrosion probes with thermocouples.

- Complete the instrumentation and controls systems for the first four probes.

- Install blowers and controls at two host utility sites.
- Continue site installation tasks, coordinating with host utilities.

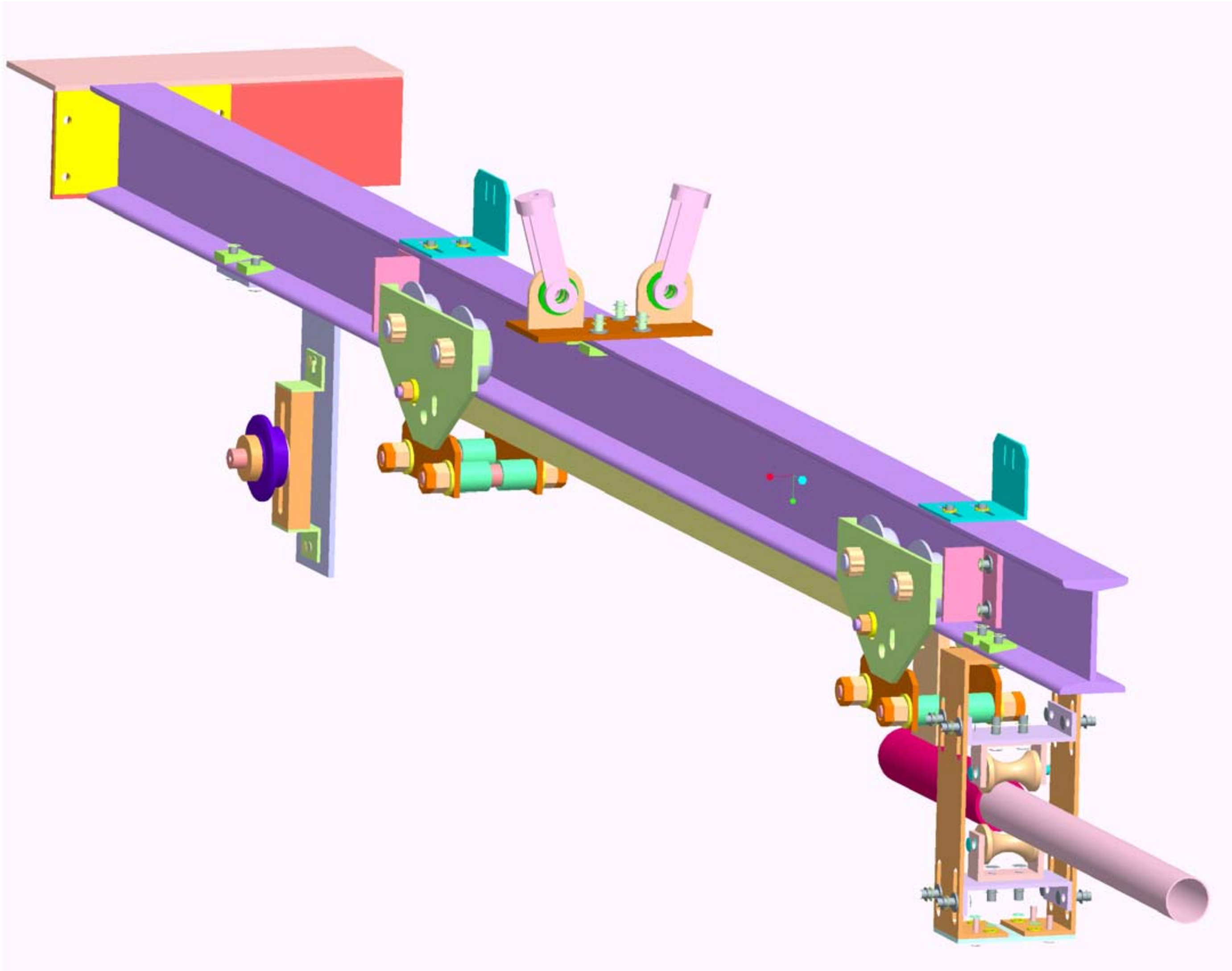


Figure 14. Illustration of corrosion probe retraction mechanism.

Task 4C Steam Loop Design, Construction, and Testing

Objectives:

The objectives of this sub-task are to design, build, and test two 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 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:

As reported last quarter, a brief outage occurred on September 7 during which a leaking socket welded fitting for a pressure tap on the attemperator piping of Section A was repaired and the packing in two instrument valves was replaced but the shorted thermocouple could not be repaired due to insufficient time to locate the short. On Tuesday September 28, the unit was shut down for a two-week outage (unrelated to the project). After returning to service in early October, it was discovered that the repaired thermocouple on Section A was connected with reversed polarity. It continues to operate but the data will have to be corrected. Section B control valve ceased to close below 50% so the section was running cooler than desired.

Early in November the socket welded fitting for a pressure tap on the attemperator piping of Section A, which has leaked twice before and been repaired, began leaking again and the attemperator had to be valved out requiring the inlet valves to be opened (resulting in the sections again running cooler than desired). This is frustrating since the duty is not severe (low temperature and pressure). Mysteriously, the control valve for Section 'B' began functioning again. It will be watched and checked at the next opportunity. On a couple of occasions, the operators erroneously released the inlet control valves from 'manual open' to 'automatic mode' resulting in brief operation at the high outlet steam temperature without the attemperator in service. This presents an overheating concern for the carbon steel attemperator piping and a much lesser concern for the thermal sleeve into the main reheat outlet pipe so the control logics were modified to prevent operator release and the system is currently running with valves open awaiting an opportunity to repair the fitting.

There was no opportunity to correct any of these problems during December. The sections continued to run cool with control valves open:

Concerns:

None.

Plans for Next Quarter:

- Repair the leaking fitting on Section 'A' pressure tap.
- Correct misconnected thermocouple.
- Check control valves on Section 'B'.
- Continue to monitor operation and collect data.

Task 5
Welding Development
(Alstom)

Objectives:

The major objectives for Task 5: Welding Development are:

- 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:

GENERAL:

A paper describing the ALSTOM Task 5 efforts regarding weldability of candidate materials for ultrasupercritical boilers was presented at the EPRI 4th International Conference on Advances in Materials Technology for Fossil Power Plants.

SAVE 12:

- A gas tungsten arc welding process using matching filler metal was finally developed and qualified for butt joints in the 2-inch OD x 0.400-inch MWT tubes cut from the SAVE 12 piping. Initial attempts had failed bend tests but imposing a relatively long, high temperature post weld heat treatment facilitated qualification. Similar difficulties have been encountered using a gas tungsten arc root and a shielded metal arc fill and this process is still under development.

- A 13.78-inch OD x 2.3-inch wall test piece was completed with matching filler and using gas tungsten arc, shielded metal arc, and submerged arc processes. Following post weld heat treatment, the weld areas will be subjected to qualification tests.

HR6W:

- The ability to develop weld processes for butt joints in HR6W tubes using the custom HR6W fillers is still in question. Joints prepared with a gas tungsten arc process passed radiographic testing but failed bending tests and also had low tensile strengths. Joints using a gas tungsten arc root and a shielded metal arc fill process failed radiographic testing because the custom filler material for the shielded metal arc welding did not run smoothly.

Inconel 740:

Special Metals made test welds using argon\helium mixed gas to judge the effect on microfissuring. While the heat affected zone of a weld using Nimonic 263 filler had microfissures, this zone in a weld using Inconel 740 filler and the weld metal of both mockups were crack free. The base metals used in the two trials were from different heats and subsequent investigations indicated that there is heat-to-heat variability regarding sensitivity to heat affected zone microfissuring. More weld trials are planned to characterize this behavior.

The ductility of Inconel 740 weldments also appears to be affected by the shielding gas used in that a mixture of 75% Argon and 25% Helium facilitated producing welds that would pass a 2T bend test whereas 100% Argon shielded welds failed. As an added complication, helium shielded welds developed microfissures in heat affected zones while argon shielded ones did not.

CCA 617:

Planning meetings were held with representatives of VDM and Special Metals to address the problems with shielded metal arc welding of CCA 617. VDM provided a list of critical parameters that need to be checked when using the matching filler metal and discussions are planned between ALSTOM and Special Metals welding experts regarding the cracking problems encountered when using Inconel 177 filler.

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 might prove insurmountable for this program.
- Inconel 740 appears to have a heat-to-heat sensitivity with regards to microfissuring which could require additional constraints on composition.

Plans for the Next Quarter:

- Continue qualification efforts on SAVE 12 pipe butt weld processes using matching filler metals.
- Continue qualification efforts on HR6W tube butt weld processes using matching filler metals.
- Determine efforts required to develop a gas metal arc welding process using Type 347 filler to make butt joints in Super 304H tubing.
- Continue to study problems with shielded metal arc welding of CCA 617 thick plates.
- Continue to study the problems with heat affected zone microfissuring in Inconel 740.

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:

None.

Concerns:

None.

Plans for the Next Quarter:

Prepare test samples from SAVE 12 tube and pipe welds that utilized matching filler metals for ORNL evaluation.

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:

1. This effort was completed and, using Gleeble hot-ductility tests and spot-varestraint tests, demonstrated that Inconel 740 is highly susceptible to liquation cracking in weld heat affected zones. Moreover, the non-homogeneous characteristics of this material might tend to increase the difficulties with liquation cracking.
2. This effort was also completed by using Gleeble hot-ductility tests and demonstrated that Inconel 740 heat affected zones were not susceptible to ductility dip cracking.
3. The evaluation of post weld heat treatment cracking susceptibility is in progress using Gleeble stress-relaxation testing and high-temperature tensile testing.

Concerns:

None.

Plans for the Next Quarter:

Continue evaluation of post weld heat treatment cracking susceptibility of Inconel 740 at Edison Welding Institute.

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:

Gas tungsten arc and shielded metal arc processes for making dissimilar metal weld butt joints between HR6W and Save 12 tubing were developed and samples are being subjected to qualification tests. The gas tungsten arc process used Inconel 82 filler whereas Inco-Weld A was used for the shielded metal arc process.

Concerns:

None.

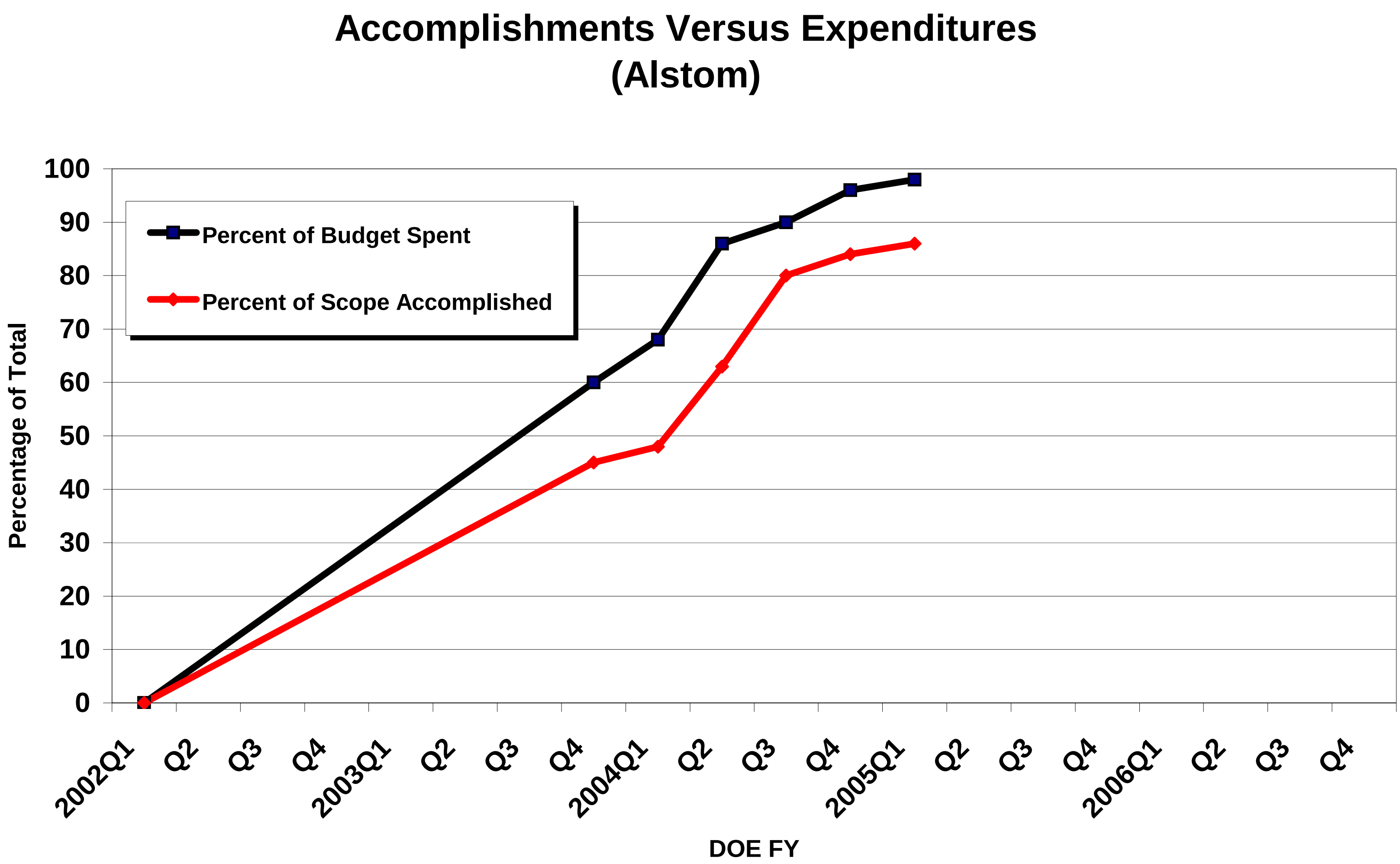
Plans for the Next Quarter:

- Complete CCA 617/Super 304H test samples.
- Continue work to qualify dissimilar metal joints between the HR6W and SAVE12 tubing.

Task 5: Welding Development - Milestone Chart

(DOE Fiscal Year Basis)
(percentages indicate fraction of workscope completed as of 2005Q1)

		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.				△		80%							▲							
	• Preliminary weld trials and parameter optimization – thick section.				△		80%							▲							
5C	Preparation of Laboratory Samples																				
	• Material preparation.					△		75%						▲							
	• Sample fabrication.						△	75%						▲							
5D	Weldability Testing												△	20%			▲				
5E	Examination of Dissimilar Metal Welds.																				
	• Weld trials										△	35%		▲							
	• Metallurgical analysis											△	0%			▲					
	• Analysis and test case.											△	0%				▲				


Accomplishments Versus Expenditures
(Alstom)
Percent of Budget Spent
Percent of Scope Accomplished
Percentage of Total
100
90
80
70
60
50
40
30
20
10
0
2002Q1
Q2
Q3
Q4
2003Q1
Q2
Q3
Q4
2004Q1
Q2
Q3
Q4
2005Q1
Q2
Q3
Q4
2006Q1
Q2
Q3
Q4
DOE FY

Task 6
Fabrication
(B & W)

Objectives:

The objective of Task 6 is to establish boiler fabrication guidelines for the high temperature, 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: <u>Riley Power, Inc.</u>

- Riley Power Inc. is currently working with Foster Wheeler who has been subcontracted to conduct controlled strain/recrystallization studies of HR6W and SAVE12 materials.

- Samples of the 2" OD HR6W and SAVE12 have been bored out to a wall thickness 0.200" in preparation for swaging.

Figures 1 and 2 Images showing longitudinal sections machined from a SAVE12 pipe (left) and a tube machined from a SAVE12 section (right).

Concerns:

None.

Plans for the Next Quarter:

- Swaging of the tubes from 2.0" down to 1 ¾" OD and from 1 ¾" OD down to 1 ½" OD will be performed in January 2005.

- Pending review of the project budget, Riley is 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.

- A fabrication mockup, built to demonstrate the progress that has been made while studying the fabricability of the CCA 617 and Super 304H materials, was displayed at the EPRI sponsored 4th International Conference held October 25th – 28th in Hilton Head, SC during October (see Figure 1). For its construction, a two-inch thick CCA 617 plate was formed to simulate a header shape and drilled to accept nipples. CCA 617 and Super 304H tubing sections were bent into typical nipple configurations and welded into the header. Additional features, including a swaged tube section and a dissimilar metal weld, were also incorporated.

- Fourteen sets of tapered tube samples have been prepared for metallurgical examinations. These include seven sets from each of the CCA 617 and Super 304H tubing materials and represent the as-formed conditions as well as 1, 10, and 100-hour exposures at 1300^{o}F and 1400^{o}F for the Super 304H and 1400^{o}F and 1500^{o}F for the CCA 617.

Concerns:

None.

Plans for the Next Quarter:

- Make the series of Super 304H and CCA 617 U-bend specimens required for Task 2 testing.

- Complete the examination of the tapered tubes used for the cold working studies.

- Determine the sensitivity of Super 304H to strain induced embrittlement.

- Complete the demonstration mockup.

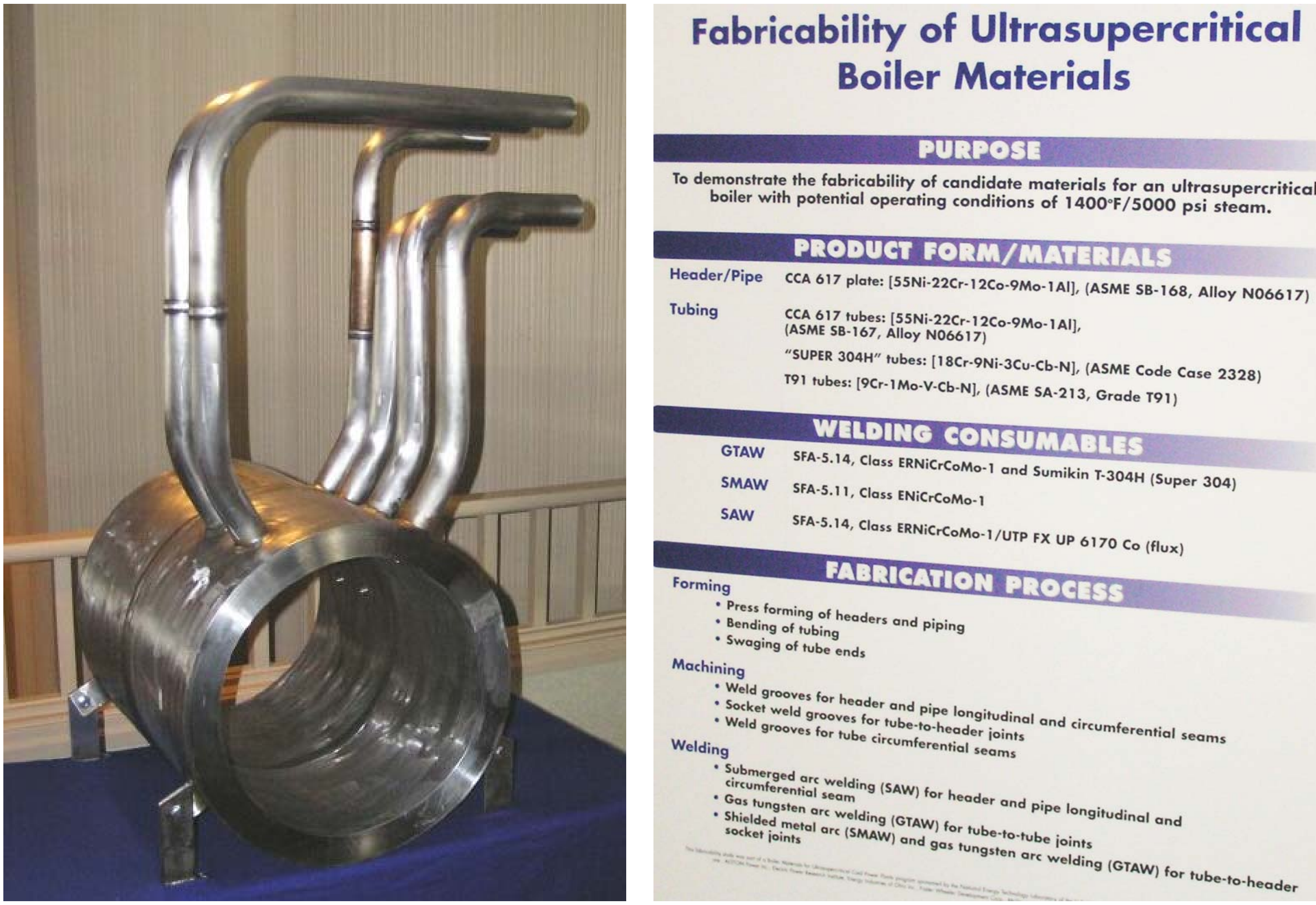


Figure 1. Image showing Alstom's mockup assembly that was built to demonstrate the progress that has been made while studying the fabricability of the CCA 617 and Super 304H materials.

Progress for the Quarter: <u>Foster Wheeler</u>

Recrystallization Study:

- Samples of the strained 230 material were exposed to 1600°F for 100 hours. As shown in Figure 1 of the attached file, recrystallization occurred at the locations with 41.8 (top photomicrograph) and 25.4 (bottom photomicrograph) percent outer-fiber-strain (OFS), with the location of higher strain exhibiting a greater degree of recrystallization. No recrystallization was evident at the location of 17.1 percent OFS; however, in evaluating the specimen section between the 17.1 and 25.4 percent OFS, the location displaying the onset of recrystallization, illustrated in Figure 2, was noted.

- Based on the results of the 1600°F/100 hour exposure, a series of additional thermal exposures (e.g., 250, 400, 550, 600, and 700 hours) were initiated at 1500°F to determine how long it would take to produce the same degree of recrystallization as at 1600°F in 100 hours. As shown in Figures 3 and 4, respectively, the degree of recrystallization at the 41.8 and 25.4 OFS locations was similar after 700 hours at 1500°F as at 1600°F in 100 hours. Furthermore, evaluation of the specimen section between 17.1 and 25.4 percent OFS revealed the onset of recrystallization at a similar area as in the specimen exposed at 1600°F for 100 hours.

- Using these results, a Larson-Miller analysis was performed to determine the exposure times for producing similar degrees of recrystallization at various temperatures, and the results of the analysis are presented in the Table I. Selected thermal exposures will be performed for some of the estimated times to verify the results. In addition, a thermal exposure will be performed at a temperature higher than 1600°F for a prolonged period of time to determine if recrystallization occurs at OFS levels less than 20 percent.

Concerns:

None.

Plans for the Next Quarter:

- Next quarter, FW plans to complete the characterization of the 230 strained materials following thermal exposure. FW also plans to perform a first thermal exposure (temperature/time conditions not yet established) on the HR6W and SAVE 12 strained material and to characterize the resulting microhardness and microstructure. After assessing the data, a second thermal exposure of these materials will be planned and conducted.

Progress for the Quarter: B&W

- Microstructural specimens of alloy 230 U-bends produced with strains of 13.3%, 20%, and 33.3% were prepared for examination.

- Materials to build a fabrication demonstration article were selected from inventory, measured and prepared for welding and assembly.

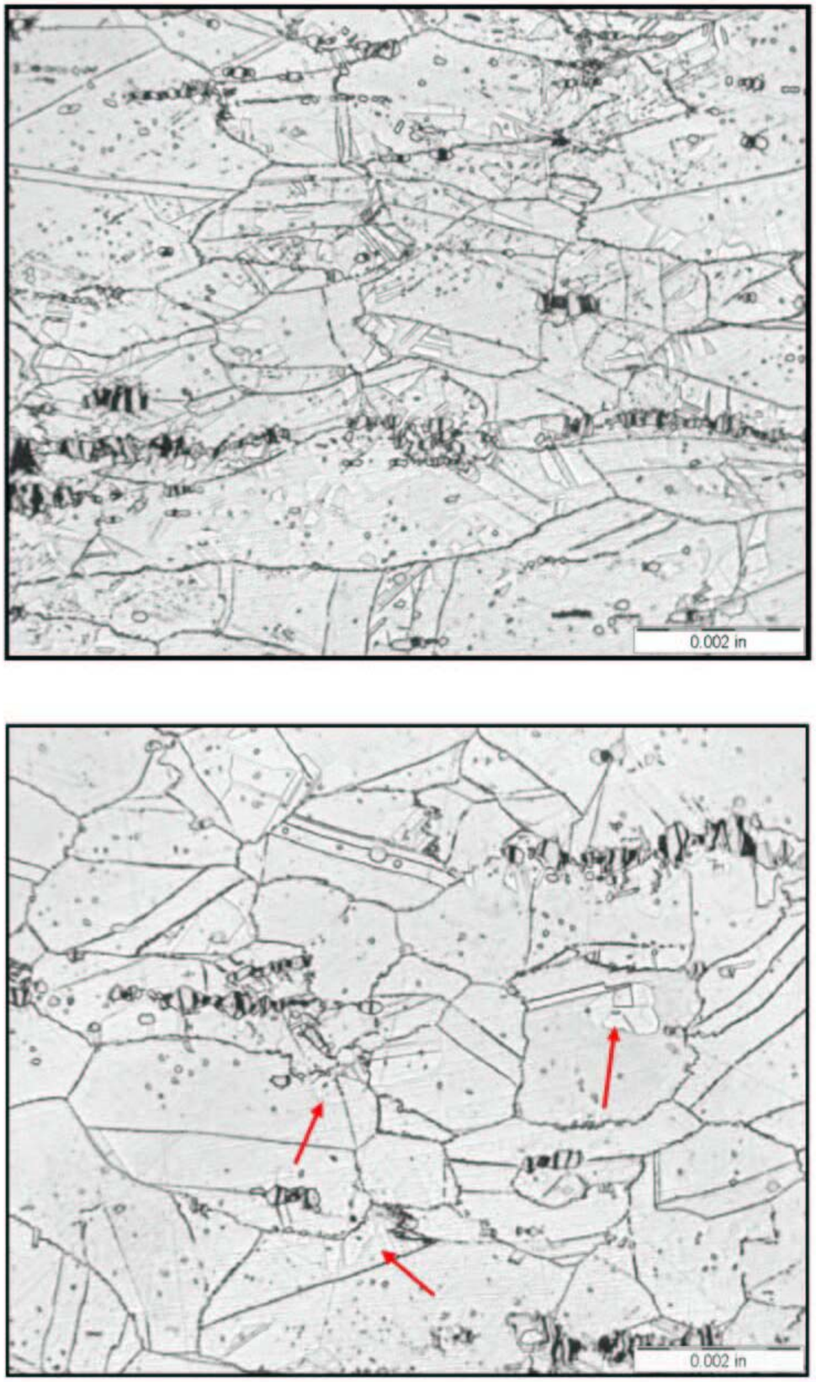


Figure 1

Recrystallization at the 41.8 (top) and 25.4 (bottom) OFS locations in the 230 specimen exposed at 1600°F for 100 hours.

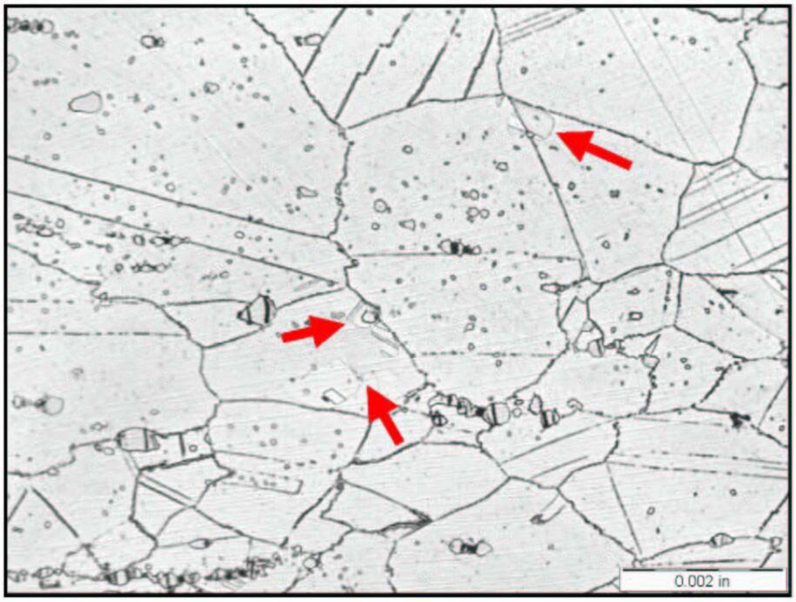


Figure 2

Onset of recrystallization in the 1600°F/100 hour 230 specimen in a section between the 25.4 and 17.1 percent OFS locations.

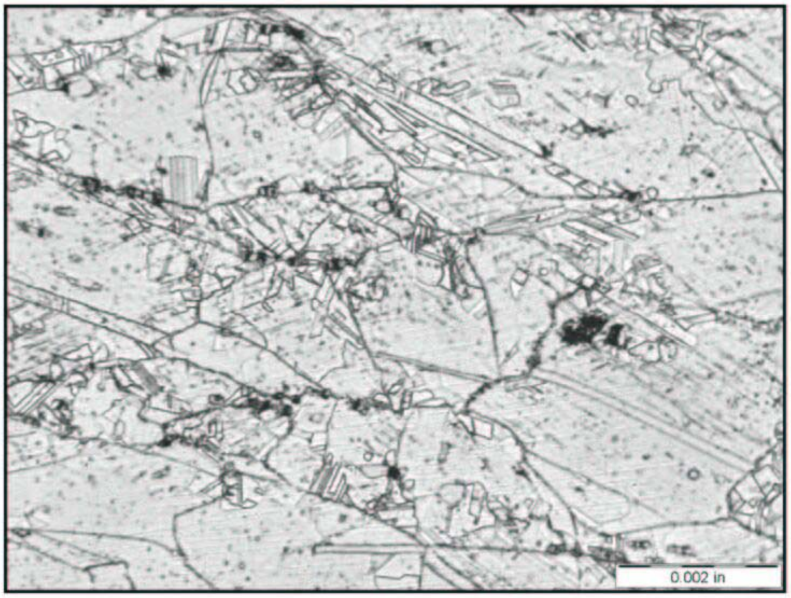


Figure 3

Comparison of the degree of recrystallization at the 41.8 percent OFS position in the Alloy 230 samples exposed at 1500°F/700 hours (top) and 1600°F/100 hours (bottom).

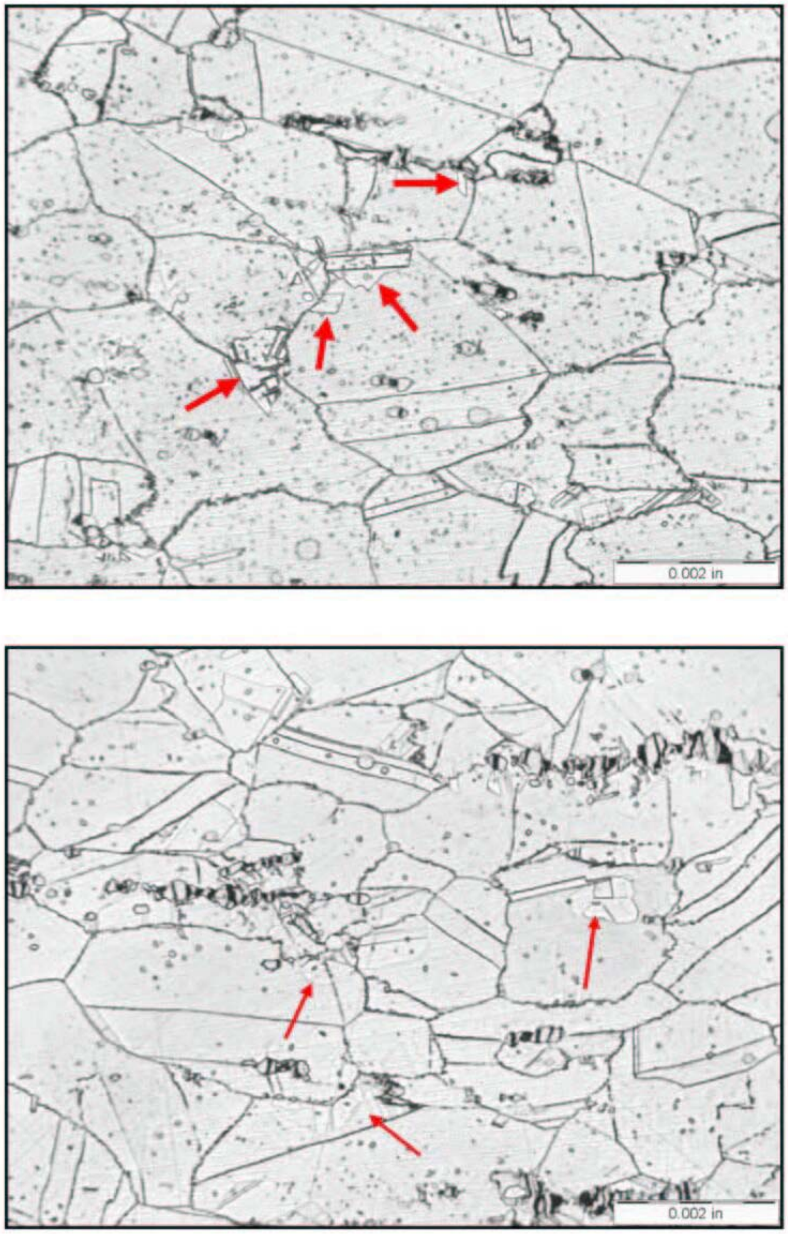


Figure 4

Comparison of the degree of recrystallization at the 25.4 percent OFS position in the Alloy 230 samples exposed at 1500°F/700 hours (top) and 1600°F/100 hours (bottom).

Table I

Results of Larson-Miller analysis showing exposure times to
produce similar degrees of recrystallization at various temperatures

Temperature (°F)	Time "t" (hrs)
1100	20,490,467
1200	984,292
1300	66,764
1400	6,048
1500	700
1550	258
1600	100
1650	40.5
1700	17.1
1800	3.4

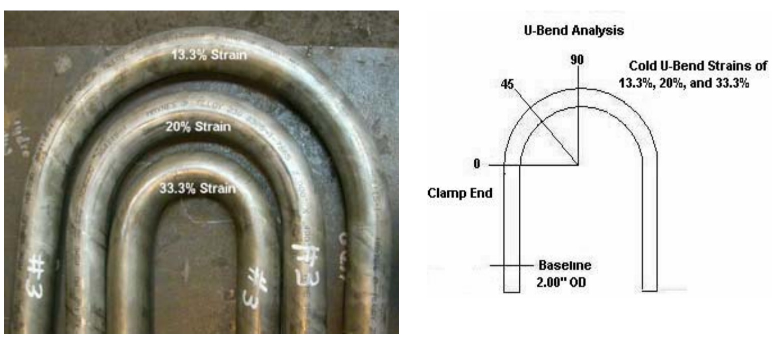


Figure 1 Showing locations where microstructural specimens were cut from alloy 230 U-bends with strains of 13.3%, 20%, and 33.3%.

Concerns:

None.

Plans for the Next Quarter:

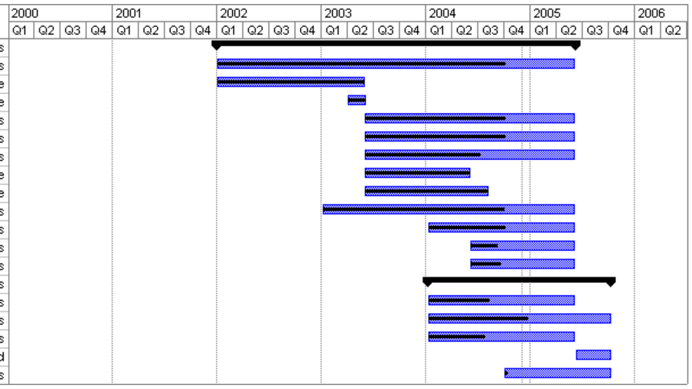
- Microstructures of alloy 230 bends (extrados, neutral axis, and intrados) will be examined, characterized, and compared to microstructures produced in the controlled strain/recrystallization/precipitation studies.

- Swaging trials with Alloy 230 tubes machined to 2” OD X 0.200MW are planned.

- Construction of an Alloy 230 (fabrication) demonstration article will begin.

TABLE 6
Schedule and Progress

ID	Task Name	Start	Finish	Status
2	**6A: Fab Trials for SH**	Tue 1/1/02	Mon 6/6/05	In Progress
3	6A.1 SH Trial	Tue 1/1/02	Fri 6/3/05	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	Fri 6/3/05	In Progress
7	Cold Bending Trials	Mon 6/2/03	Fri 6/3/05	In Progress
8	Cold Swaging Trials	Mon 6/2/03	Fri 6/3/05	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	Fri 6/3/05	In Progress
12	6A.3 SH: Met Test & Eval	Fri 1/9/04	Fri 6/3/05	In Progress
13	6A.3.1 Mic Bends&Welds	Fri 6/4/04	Fri 6/3/05	In Progress
14	6A.3.2 HT Studies&Mic	Fri 6/4/04	Fri 6/3/05	In Progress
15	**6B: Fab Thk Wall Comp**	Fri 1/9/04	Thu 10/6/05	In Progress
16	6B.1 Thick-Wall Fab Trial	Fri 1/9/04	Fri 6/3/05	In Progress
17	6B.2 Reporting	Fri 1/9/04	Thu 10/6/05	In Progress
18	6B.3 Thick-Wall Comp	Fri 1/9/04	Fri 6/3/05	In Progress
19	6B.3.1 Met Analysis	Mon 6/6/05	Thu 10/6/05	Planned
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 7F: Process Optimization

Objective:

Perform coating process optimization at an intermediate scale between laboratory and commercial size.

Progress for the Quarter:

Part 1: B&W Effort

None.

Part 2: Alstom Effort

A technical paper entitled "Use of Surface Modification of Alloys for Ultrasupercritical Coal-fired Boilers" by Goodstine and Nava was presented at the EPRI-sponsored Fourth International Conference on Advances in Materials Technology for Fossil Power Plants, October 23-25, 2004.

Task status presentation was made at the November Program Steering Committee meeting.

Concerns:

Availability of released funds to support Task 7 activities at B&W and ALSTOM is a concern.

Activities Planned for Next Quarter:

Pending funds release, complete detailed analysis of sample specimens.

Task 7H: Specimens for Field Corrosion/Oxidation

Objective:

Provide externally and internally coated specimens for inclusion in corrosion/oxidation testing under Tasks 3 and 4.

Progress for the Quarter:

- Sample coupons coated with “Nanocomp” were exposed in laboratory tests by Foster Wheeler under Task 4 laboratory evaluations. The coating was reported to fall off during routine refreshing of the ash coating used in testing.

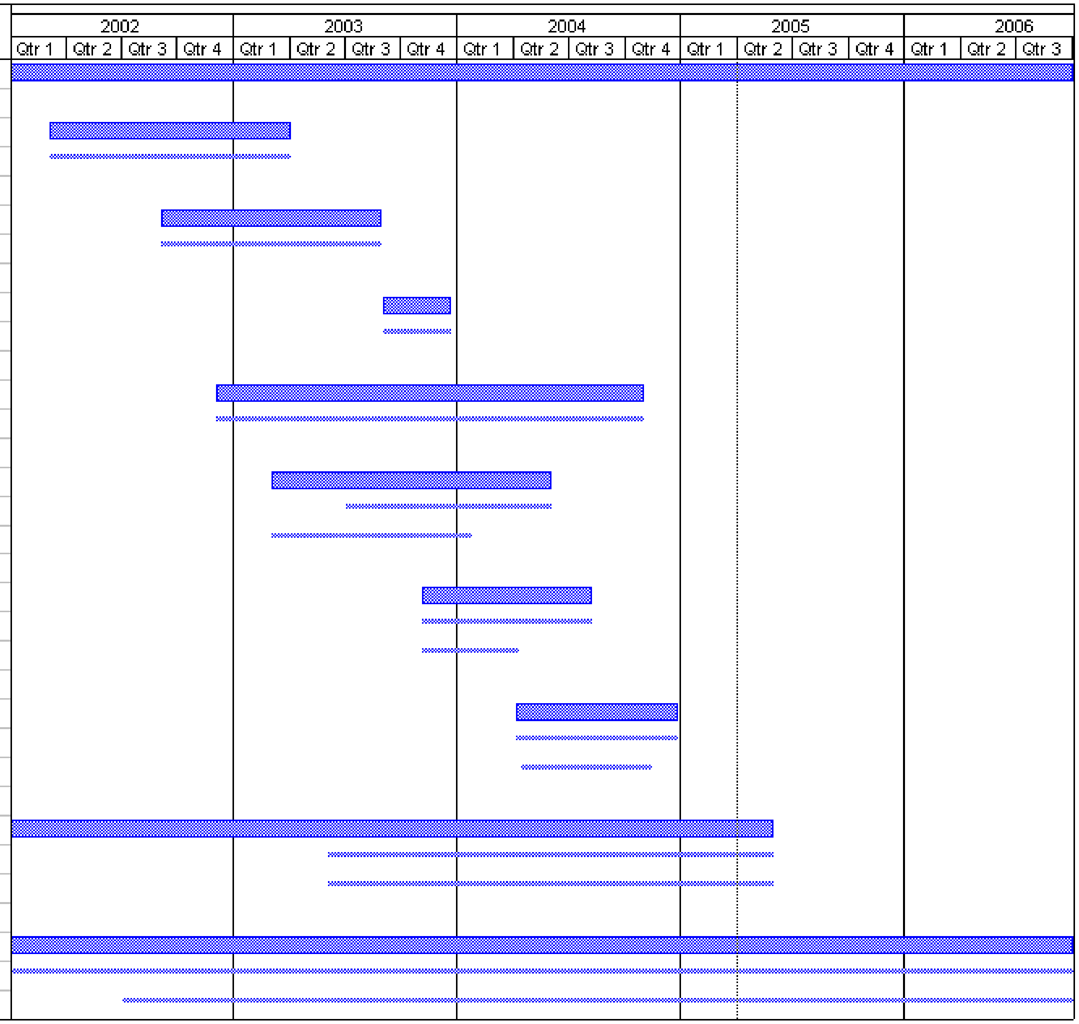
Concerns:

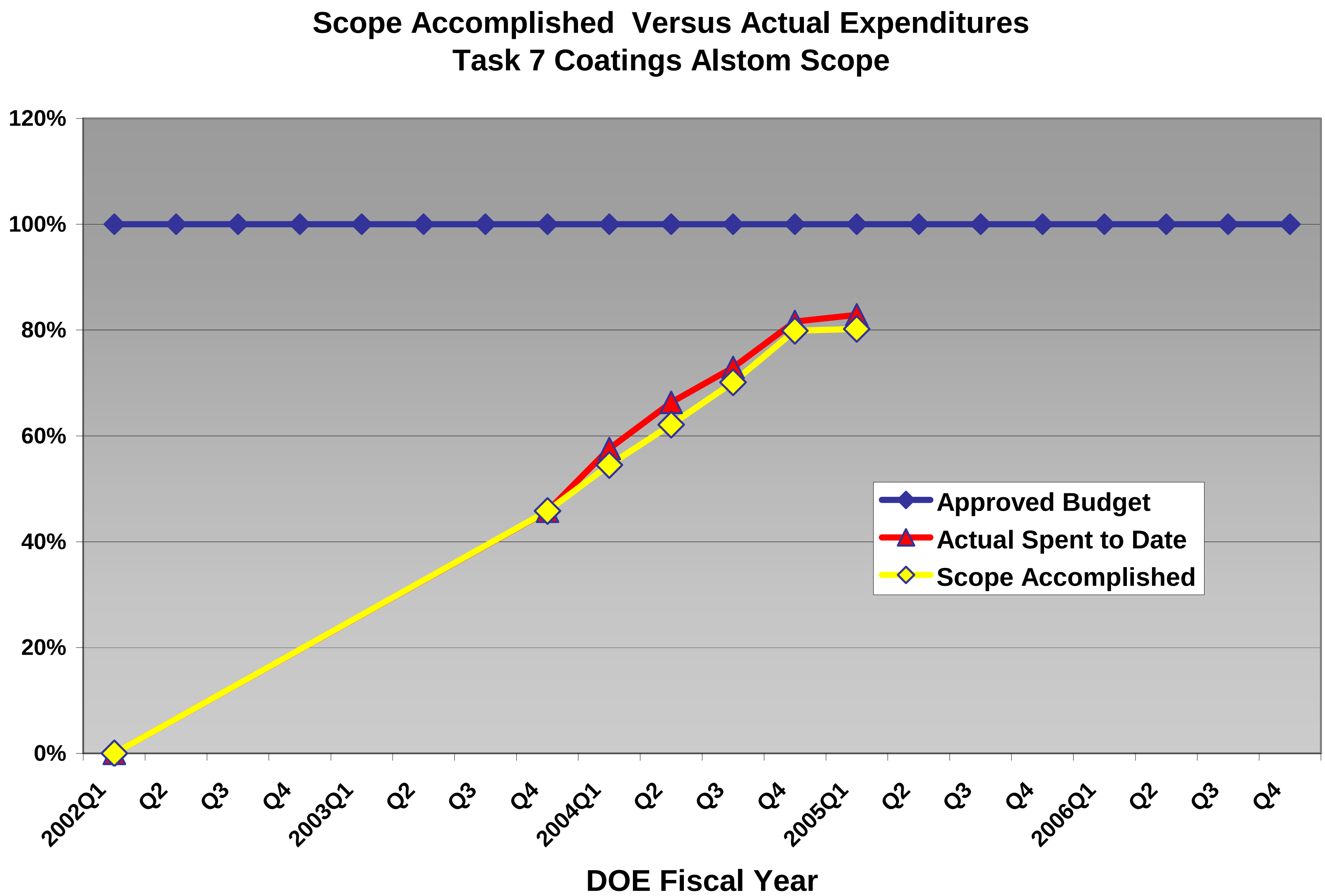
None.

Plans for the Next Quarter:

Discuss results seen with “Nanocomp” with supplier to establish the problem with bonding to the specimen.

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	60%
Task 7E: Process Scale Up - Preliminary Trials	
Alstom Task 7E: Process Scale Up - Preliminary Trials	100%
B&W Task 7E: Process Scale Up - Preliminary Trials	87%
Task 7F: Process Optimization	
Alstom Task 7F: Process Optimization	75%
B&W Task 7F: Process Optimization	87%
Task 7G: Manufacturing Recommendations	
Alstom Task 7G: Manufacturing Recommendations	
B&W Task 7G: Manufacturing Recommendations	30%
Task 7H: Specimens for Field Corrosion/Oxidation	
Alstom Task 7H: Specimens for Field Corrosion/Oxidation	75%
B&W Task 7H: Specimens for Field Corrosion/Oxidation	55%
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
120%
100%
80%
60%
40%
20%
0%
Approved Budget
Actual Spent to Date
Scope Accomplished
2002Q1
Q2
Q3
Q4
2003Q1
Q2
Q3
Q4
2004Q1
Q2
Q3
Q4
2005Q1
Q2
Q3
Q4
2006Q1
Q2
Q3
Q4
DOE Fiscal Year

Task 8
Design Methods and Data
(Alstom)

Objectives for Task 8:

- 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:

- Presented a paper at the EPRI 4th International conference on Advances in Material Technology for Fossil Power Plants entitled "Design and Life Assessment of Ultrasupercritical Boilers" to highlight some of the shortcomings of existing code methodologies and present the wall thickness calculation which is presently seeking code approval.
- A scope revision was proposed for Task 8 to include an activity on cyclic analysis of ultrasupercritical boiler components made of various candidate materials using a recently published simplified assessment methodology. The method enables shakedown and ratcheting boundaries to be determined with relative ease for complex components and would allow the factor of safety against occasional severe thermal events to be assessed. Based on approval from the steering committee, this activity will be included and will commence in January pending funding release from DOE.

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 plotted and issued creep test results, for the HR6W material, in the form of percent creep strain versus time to rupture from the ORNL data. To supplement that work, we have also plotted stress versus creep rupture time curves for the eight completed creep test results for the HR6W material, as listed on the USC material properties data transfer website. The test values have been compared to calculated values, using the latest creep rupture and Larson-Miller data from Sumitomo literature, dated February 2004. The test results show reasonably good correlation with the Sumitomo data for two tests each, performed at 650, 700 and 725°C. The single test results at 775 and 800°C, show lower creep rupture values than those calculated from the Sumitomo data. There are no test results presently available for SAVE 12, the other material assigned to Riley.

In conversations with Sumitomo personnel, at the October 2004 EPRI conference on materials, we learned that the creep rupture strength of HR6W material is very sensitive to the actual percentage of Tungsten present in a given heat, within the specified range of 4 to 8 percent.

Due to funding limitations, the other participants did not perform any work on this subtask.

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 structural feature tests that should commence in the next quarter.

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:

As reported last quarter, funding issues for both ALSTOM and B&W hampered progress. Also as reported last quarter, only a few test results are presently available on the ORNL data transfer web site, which limits the progress that could be achieved. Since structural feature (e.g. notched bar) tests have only recently commenced, then it is unlikely that significant progress will be made on this subtask for at least another six months.

Concerns:

Timely availability of creep data on ORNL web site and results of notched bar creep rupture tests. Availability of funds to support Task 8 activities at B&W and ALSTOM also remains a concern.

Plans for the Next Quarter:

Monitor material data web site to see if sufficient data is available to initiate a modeling activity.

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:

During the quarter, Riley Power Inc. submitted a second draft version of their portion of the weld literature review summary report for comments. Based on preliminary review comments, we added a summary section to the testing and assessment portion of the report. This revised version of the preliminary document is essentially complete, and will be submitted to the subtask leader at Alstom.

Concerns:

Timely release of project funds is required to ensure that ALSTOM can work on this activity.

Plans for the Next Quarter

In the next quarter, Riley Power will add a section on dissimilar metal welds to the report, and expand the section on weld strength reduction factors, based on promised, available papers from Carl Jaske. We will also add review summaries of applicable, pertinent papers on welds, presented at the October 2004, EPRI, 4th International Conference on Advances in Materials Technology for Fossil Power Plants. ALSTOM will work on their portion of the weld literature review and work with Riley Power to issue the completed summary report.

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:

Minimal activity responding to questions raised by submission to the Code Committee. Code Committee met in December and proposed revision to the code will be sent out for ballot in January.

Concerns:

None.

Plans for the Next Quarter:

Continue to seek Code acceptance of proposed revisions.

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 Task:

- Completed Fourth Quarterly Report for 2004.
- Completed Monthly Reports for October and November, 2004.
- Monthly conference calls were held and the discussions were documented.
- Facilitated the EPRI Fourth International Conference on Advances in Materials Technology for Fossil Power Plants. This conference was co-sponsored by DOE/OCDO and included presentations by many of the participants of this project. The conference was held at the Hilton Oceanfront Resort in Hilton Head Island, South Carolina on October 26-28, 2004.

Concerns:

None.

Plans for the Next Quarter:

- Conduct meeting on Oxygen Firing in Washington on Feb 14, 2005.
- Conduct a Steering Committee Meeting in March timeframe.
- Issue monthly reports and hold conference calls as required.