the ENERGY lab

PROJECT FACTS

Advanced Research Materials

Materials for Advanced Ultra-Supercritical Steam Power Plants

Background

The first ultra-supercritical (USC) steam plants in the U.S. were designed, constructed, and operated in the late 1950s. The higher operating temperatures and pressures in USC plants were designed to increase the efficiency of steam plants. However, materials performance problems forced the reduction of steam temperatures in these plants, and discouraged further developmental efforts on low heat-rate units. Increasing fuel costs and interest in the reduction of emissions rekindled interest in USC steam plants in the 1980s, and the Electric Power Research Institute (EPRI) initiated significant developmental efforts that were taken further in Europe and Japan.

Rising natural gas and petroleum fuel costs caused a renewal of interest by U.S. utilities in coal-fired power generation. Future limits on emissions from these plants are anticipated and must be addressed in current research endeavors. Several USC power plants are now achieving greater efficiencies in operation around the world, and current development interest is focused on advanced ultra-supercritical (AUSC) operations, with temperatures up to 1,400 degrees Fahrenheit. The increased efficiency of USC steam cycles and additional increased efficiency associated with AUSC steam cycles have the potential to reduce carbon dioxide (CO_2) emissions from coal combustion by up to 30 percent. A consortium of all the major U.S. boilermakers was assembled to identify the materials technology necessary to enable implementation of AUSC power generation. The Department of Energy's (DOE) National Energy Technology Laboratory (NETL) is partnering with Oak Ridge National Laboratory (ORNL) to perform research designed to support the materials data generation needs of that consortium.

The choice of alloys used for high-pressure components in U.S. steam boilers is governed by the strength/temperature limits set by the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code. There is a relatively limited range of alloys actually used, but for these there is abundant expertise in most aspects of manufacture, fabrication, service behavior, and repair. The limiting factor for the ferritic steels in use is their high-temperature corrosion behavior (fireside and steam side). The austenitic steels in use are approaching their mechanical property limits at the higher-temperature range of U.S. steam generating practice. A move to steam temperatures and pressures significantly higher than those employed in current U.S. power plants will necessitate use of the newer ferritic and austenitic steels developed (and in service) in Europe and Japan, as well as the introduction of nickel (Ni)-based alloys for the highest-temperature components.

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PARTNERS

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PROJECT DURATION

Start Date
09/29/2009

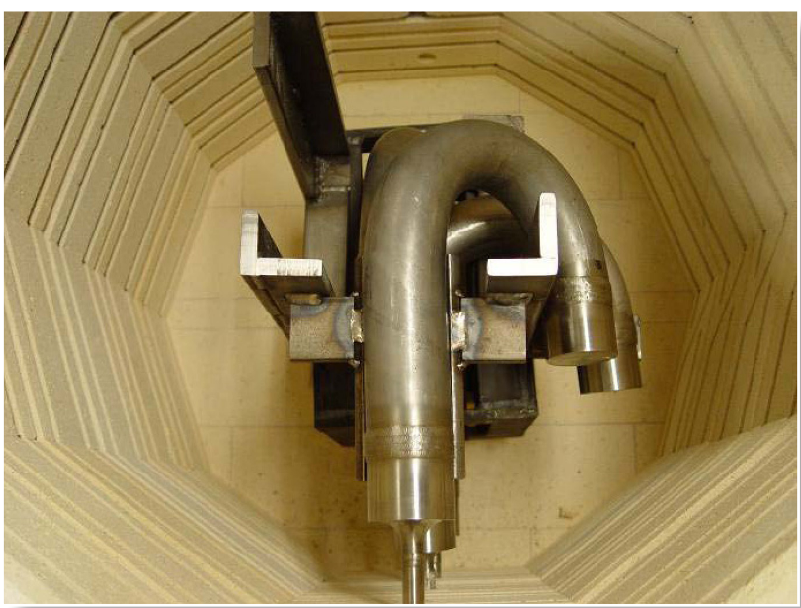
End Date
09/30/2011

COST

Total Project Value
$990,000

DOE/Non-DOE Share
$6,291,700 / $0

Inconel 740 Cold Bend Tested Samples



Alloy 617 in Cold Bend Test Rig

Project Description

This project is to develop the materials technology required to operate a power steam boiler at steam conditions up to 760 degrees Celsius (°C) and 350 bar pressure, which will decrease emissions by up to 30 percent and reach efficiencies of around 50 percent. ORNL will continue to evaluate the long-term behavior of candidate alloys, to investigate the effects of processing variables, to provide fundamental research in microstructural evolution at very long times using electron microscopy and computational thermodynamics, and to provide data necessary to produce material models.

Researchers will measure oxidation kinetics pertinent to the range of conditions expected in AUSC steam boiler operation and characterize the evolution of scale morphologies to provide input on ultimate failure due to high oxidation rates or scale spallation (fragmentation). The team will provide useful, reliable corrosion data for AUSC operating conditions for currently-used classes of alloys, along with alloys new to steam boiler practice, as well as an underpinning rationale for any differences from current steam oxidation behavior. Information concerning the rate and mode of corrosion of the alloy classes currently used in steam at temperatures and pressures higher than current conditions (565°C, 248 bar) is significantly lacking, and information for the newer alloys is almost nonexistent.

Goals and Objectives

The goal of this project is to develop the materials technology required to design, construct, and operate an USC steam boiler with reduced heat rate and increased efficiency. One main objective is to obtain ASME code approval for the materials and methods employed. The research undertaken here will provide an essential database to the designers, manufacturers, and users of USC steam plants. It will also generate the creep data and certain other mechanical property data, and develop the metallurgical understanding needed for ASME Code approval.

Accomplishments

This project is a continuation of research ORNL has performed over multiple years. During past funding periods, researchers began long-term creep-rupture testing, performed tensile testing, and performed microstructural characterization of Inconel 740. The team began creep testing of full-sized tube bends of Alloy 617 by internal pressurization, with test duration approaching 10,000 hours. Researchers also initiated preliminary testing of Haynes 282, a new high-strength Ni-based alloy of interest to boiler manufacturers. The research team initiated tensile and creep testing as part of a systematic characterization of cold-work effects. The team completed exposures to 4,000 hours of candidate alloys in steam at 600 °C with 1 and 17 bar pressure and at 750 °C with 17 bar pressure, with analysis of oxidation kinetics and scale morphologies.

Benefits

Scientific understanding of the effects of high temperatures and pressures on these advanced materials will provide a basis for the specification, design, fabrication, operation, and maintenance of AUSC steam power plants. The development of AUSC power plants will provide significant benefits in increased fuel efficiency and reduced CO_2 emissions, helping the U.S. to conserve fossil fuels and manage emissions.