

Fossil Materials and Repair - Program 87

Program Overview

Program Description

Today's fossil power plants are increasingly adopting market-driven operating strategies such as cycling, pushing for maximum output during peak price periods, and frequent fuel switching to take advantage of spot market opportunities. These practices can accelerate material damage in major power block components. The ability to accurately predict the remaining life of components allows for optimized maintenance and replacement strategies, increased availability, and greater profitability.

The Electric Power Research Institute's (EPRI's) Fossil Materials and Repair program (Program 87) provides the integrated materials selection guidance, corrosion mitigation methods, and repair techniques needed to improve equipment performance, reliability, and profitability.

Research Value

Safety and availability loss due to failures are two key issues driving R&D on major fossil power plant components, especially in older plants. EPRI's Major Component Reliability programs provide data on critical material degradation mechanisms, conduct materials and chemistry-related R&D for advanced generation technologies, and quantify the benefits of chemistry improvements. The programs help utilities balance the risks and costs of the largest, most costly equipment, and focus on using proven technologies to create solutions. Members of the Fossil Materials and Repair program can use the R&D to:

- Increase availability through better understanding of plant materials
- Eliminate repeat failures, minimize equipment damage, and reduce outage frequency and duration by utilizing improved knowledge of damage mechanisms and life assessment methods
- Reduce failures from high- and low-temperature corrosion
- Obtain in-depth knowledge of advanced ferritic and austenitic alloys and processes used to fabricate and join these alloys
- Utilize new and advanced repair technologies
- Maximize component life by improved materials selection guidance and procurement specifications

Approach

Through a continuum of materials and repair guidelines, handbooks, and workshops, the program helps manage and reduce the operating risks associated with material degradation and failure. Projects develop resources to estimate remaining life, assess and conduct state-of-the-art repairs, decide on replacement materials, and address costly corrosion and erosion problems faced in real-world business settings.

- Research into availability increases through improved materials performance focuses on all aspects of materials used in power production, including degradation, failure analysis, selection, component life assessment, and advancements in materials technologies. Key areas of research include materials guidelines, failure analysis guidelines, materials selection and advancements, and component life prediction.
- Developments and repair solutions in fossil repair applications are provided to members via demonstrations, procedures, reports, conferences, and workshops. Deliverables are targeted to provide applications technologies to extend component life, reduce repair costs, improve materials performance, and reduce downtime for repair activities.
- R&D of reliability of materials in corrosive, abrasive, and high-temperature operation is aimed at reducing corrosion in power plant piping, heat exchangers, boiler tubing, and other components, which costs power companies millions of dollars each year, through improved understanding of corrosion mechanisms, innovative coatings assessments, and the development of guidelines.

Accomplishments

EPRI's Fossil Materials and Repair program has been a proactive industry leader in all aspects of plant materials performance, repair and welding technology development, and corrosion mitigation.

- Industry leadership in addressing fabrication, installation, welding, and degradation of creep-strength-enhanced ferritic steels and advanced austenitic stainless steels
- Development of a comprehensive International Boiler Metallurgical Guideline
- Guidance on remaining life of austenitic stainless steel materials used for superheater and reheater tubing applications
- Comprehensive Steam Turbine Metallurgical Guidelines
- Welding guidelines for boiler applications and advanced ferritic and austenitic alloys
- Series of metallurgical handbooks (Grade 11, Grade 22, X20, carbon steels, and stainless steels)
- New models for assessing oxide growth and exfoliation
- New automated welding technologies for superheater and reheater repair
- Innovative solutions for dissimilar metal weld damage repair

Current Year Activities

The program R&D for 2010 will focus on key member issues dealing with stainless tubing materials, creep-fatigue damage, improving failure analysis, dissimilar metal weld damage and repair, high-temperature weldment strength, and erosion/corrosion issues in superheaters/reheaters. Specific efforts will include:

- Strain-induced precipitation hardening (SIPH) in stainless steels
- Improved methodology for creep-fatigue damage and life assessment
- New handbooks on precipitation-hardened and advanced stainless steels
- Repair methods for dissimilar metal welds (DMWs)
- Improved productivity welding processes
- Weld strength reduction factors
- Exfoliation of fine-grained austenitics

Estimated 2010 Program Funding

\$2.9M

Program Manager

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Summary of Projects

Project Number	Project Title	Description
P87.001	Availability Increases Through Improved Materials Performance	This project performs research on all aspects of plant material performance including damage mechanisms, metallurgical phenomenon, failure analysis, material selection, and component life assessment.
P87.002	Fossil Repair Applications and Welding Technology	Fossil Repair Applications and Welding Technology provides members with new repair technologies that are critical to owners for maintaining the plant, addressing emergency failures, reducing outage times, and reducing the risk of future damage. Research is conducted to address these needs through new innovative repair tools, new welding consumables, fabrication and installation guidance, productivity improvements in welding, and the performance of welded structures.
P87.003	Reliability of Materials In Corrosive, Abrasive, and High-Temperature Operation	This project performs research to understand the often complex corrosion and erosion issues related to plant materials. Solutions in the form of guidelines, technical reports, and coating technology are provided to program members.

P87.001 Availability Increases Through Improved Materials Performance (058205)

Key Research Question

Today's fossil power plants increasingly adopt market-driven operating strategies, such as cycling, pushing for maximum output during peak price periods, and frequent fuel switching, to take advantage of spot market opportunities. These new operating modes can accelerate material damage in virtually all major power plant components, including pressure parts and rotating components. Proper selection of materials and the right operating strategy can eliminate damage while increasing plant availability and reducing repair costs. To accomplish this goal, improved understanding of damage mechanisms and material degradation is needed. The construction of new plants, mainly supercritical, is utilizing new materials where specification guidance and data on performance are required.

Approach

This project focuses on all aspects of materials used in power production, including materials degradation, failure analysis, material selection, component life assessment, and advances in materials technologies. Developments in this area will be integrated with repair applications developed in Project 87.002 and corrosion and oxidation damage mechanisms evaluation in Project 87.003. Key areas of research will include materials guidelines, improved understanding of failure mechanisms, failure analysis guidelines, materials selection and advancements, and material specific life prediction methodologies and data. Joint activities with Programs 63 and 65 are utilized where appropriate to improve component life.

Impact

- Apply comprehensive metallurgical guidelines for both metallurgical property information and the tools to predict component life.
- Select optimum materials for long-term operation using materials specifications. Many advanced materials are entering the market, and utilities face decisions concerning long-term operation of components fabricated with them.
- Work with the industry leaders in addressing creep-strength-enhanced ferritic steels (Grades 91, 92, 122, 23, and 24) and advanced austenitic alloys (347HFG, Super 304H, and NF709.)
- Participate in the international development of guidelines and improved methodologies for assessing creep-fatigue damage in components, the result of unit cycling and deployment of a host of new alloys.

How to Apply Results

Members can use the research information in this project to select optimum materials for a variety of components, ranging from piping, tubing, and headers to steam turbines and discs; gain the technical basis for improving internal material procurement specifications to ensure long-term material reliability; consistently apply improved remaining-life techniques to assess component life; address advanced ferritic and austenitic alloy issues; and better understand the factors that can influence component damage and remaining life.

2010 Products

Product Title & Description	Planned Completion Date	Product Type
<p>Strain-Induced Precipitation Hardening of Stainless Steels: Precipitation of very fine niobium or titanium carbides in the matrix of stainless steels after high-temperature service following cold- or warm-forming operations causes a substantial increase in the strength of the grain, often leading to a weakening of the grain region. Intergranular fracture may then occur prematurely during high-temperature service; this often is referred to as strain-induced precipitation hardening (SIPH). Cold-forming rules in ASME do not appear to adequately address this metallurgical phenomenon. Furthermore, tramp or unspecified elements within stainless steels may exacerbate this effect. EPRI will continue research to improve the understanding of how the alloy composition and heat-treatment can be adjusted to minimize or eliminate SIPH and work within ASME and ASTM to improve controls.</p>	12/31/10	Technical Update
<p>Improved Methods for Creep-Fatigue Assessment: EPRI continues to lead an international effort to improve understanding, standardize, and predict creep-fatigue damage in components. An initial guideline for assessment of components was completed in 2009. In 2010, further development of a property database and new improved assessment methods will be studied.</p>	12/31/10	Technical Report
<p>Conducting a Failure Analysis - Case Study: The two-volume failure analysis guideline was completed in 2009, including the process and tools needed to conduct a failure analysis. This work will be augmented with a detailed case study, showing how to use the guidelines as a practical tool for members.</p>	12/31/10	Technical Update
<p>Advanced Stainless Steel Pocket Handbook: This metallurgical handbook will focus on two alloys: TP347HFG and Super304H, which now are being routinely installed as superheater and reheaters in new supercritical boilers and in some retrofit applications. This handbook will follow in the series of "pocket" handbooks that include carbon steel, Grades 11 and 22, austenitic stainless steels, and X-20, and will build off of EPRI's state-of-knowledge review of advanced austenitic alloys.</p>	12/31/10	Technical Update
<p>International Steam Turbine Metallurgical Guide Update: This work will complete a multiple-year effort to update the Steam Turbine Metallurgical Guides with more recent information and international materials. Volume 2, Materials Property Database for HI-IP and LP Rotors, will be completed.</p>	12/31/10	Technical Report
<p>Precipitation Hardening (PH) Stainless Steel Pocket Handbook: This metallurgical handbook will be focused on precipitation-hardened (PH) stainless steels routinely used in plant applications such as 17-4PH. This effort will continue the series of "pocket-sized" handbooks that cover application, standards, chemistry, physical and mechanical properties, microstructure, processing, and heat-treatment of plant materials. Past books include C-steel, Grade 11, and Grade 22.</p>	12/31/10	Technical Report

Product Title & Description	Planned Completion Date	Product Type
Review of Graphitization at Low Temperature: Graphitization is a concern in carbon steels operating at high temperatures. Recent plant experience has reported graphitization at lower-than-expected temperatures after very long-term service. In this work, these instances of low-temperature graphitization will be reviewed and evaluated against current EPRI guidelines for graphitization.	12/31/10	Technical Update
6th International Conference on Advances in Materials Technology for Fossil Power Plants: The key enabling technology for the construction of higher-efficiency power plants and reliability of current components is the development of new materials technologies. This is the sixth in a series of conferences that bring together experts from around the world who are performing research on new alloys for boilers and turbines, giving participants improved understanding of material degradation, welding and joining technology, high-temperature mechanical behavior of plant materials, and oxidation and corrosion.	12/31/10	Workshop, Training, or Conference
Low-temperature Crack Growth due to Creep Brittleness: One factor that promotes brittleness in steels is active elements (As, Sn, Sb, and P) at grain boundaries. The steelmaking practices used affect these elemental concentrations, and the increased use of scrap in most steel production processes has led to concerns over a rise in the level of these often-unspecified elements. This project provides members with a guideline to restrict active elements and work with materials standards to tighten specifications if necessary.	12/31/10	Technical Update
Material database for small specimen remaining life assessments: Long-term (200 khr+) operation of power plant piping has resulted in the potential for base metal failures during continued operation. Small-specimen extraction techniques (from P87.002) can remove limited material for evaluating the remaining life of materials, but no good database exists for quantifying the level of remaining life. This project will focus on CrMo steel piping degradation through a development of a small specimen database utilizing small punch testing (SPT), indentation creep, and miniature fracture toughness, and correlate these properties to standard specimens and materials with known damage.	12/31/10	Technical Update

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Strain-Induced Precipitation Hardening of Stainless Steel	12/31/11	Technical Report
Failure Analysis Guide Update: Standard Practices for Investigations	12/31/11	Technical Report
Advanced Stainless Steel Pocket Handbook	12/31/11	Technical Report
Guideline for Small Specimen Testing of Serviced Piping	12/31/11	Technical Report
Material database for Small Specimen Testing of Drum Materials	12/31/11	Technical Update

P87.002 Fossil Repair Applications and Welding Technology (058206)

Key Research Question

Reliable repair technologies are a key part of any organization's run-repair-replacement decisions and are invaluable to power plant owners in maintaining the plant and addressing emergency failures. Repair of damage mechanisms investigated in 87.001 and corrosion evaluations from 87.003 will be key to this project. This project incorporates two key topics: fossil plant repair applications (immediate repair needs) and advanced repair and welding technologies (focused on development of longer-reaching repair technologies, including improved welding consumables and improved understanding of weld performance).

Approach

Developments and repair solutions will be provided to members via demonstrations, procedures, reports, conferences, new products, and workshops. Deliverables include applications technologies to extend component life, reduce repair costs, improve materials performance, and reduce downtime for repair activities. Participants in this project gain direct access to EPRI's welding, materials, and power plant repair experts, as well as the collaborative expertise of fellow program participants.

Impact

- Improve practices, equipment, and methodologies to reduce the cost and time involved in repairing and replacing superheat and reheat tubing
- Provide solutions for dissimilar metal weld (DMW) repair
- Ensure quality new plant performance by using fabrication and installation guidance when working with OEMs, vendors, and architectural engineering firms
- Apply guidelines for selecting welds and processes at high temperature
- Quantification and standardization of high productivity welding processes

How to Apply Results

Members will have access to research results on advanced repair technology through guidelines and reports, such as the Fabrication & Installation Guidelines, which can be used to specify and follow fabrication practices used by vendors and OEMs. Members are encouraged to attend the conferences on welding and repair to ensure effective technology transfer. These conferences are supplemented by workshops and technical support services as required. Members will be able to use the adaptation of existing repair technology in new applications and development of repair technologies. Newly available consumable products, such as P87 filler metal, will be made available to improve welded component performance.

2010 Products

Product Title & Description	Planned Completion Date	Product Type
Repair Methods for Dissimilar Metal Welds: This project will bring together two EPRI-developed technologies as a repair solution for dissimilar metal weld (DMW) damage — P87 filler metal and the limited-access automated superheat/reheat repair tool. Repair of a DMW will be demonstrated with P87 bare wire filler metal, and metallurgical evaluation and qualification of the P87 filler metal joint will be performed.	12/31/10	Technical Report
Automated Repair of Superheat & Reheat Tubing: This work is the completion of a multi-year development to develop an arm's-reach tool for remote automated welding within a superheater/reheater tube bundle. For this project, the prototype tool will be demonstrated in a field application.	12/31/10	Technical Report

Product Title & Description	Planned Completion Date	Product Type
<p>Narrow-Groove GMAW & FCAW for Improved Productivity: Narrow-groove GMAW and FCAW are being considered to improve productivity in installation of large-diameter piping. However, the advantages of these techniques have not been fully quantified both in terms of productivity (welding time) and quality (properties of welded joint). Furthermore, a standard root geometry has not been agreed to, thus uncertainty exists in what is the best joint to choose. This project will be conducted to quantify the productivity improvement of using GMAW and FCAW and to recommend best practices for joint geometry.</p>	12/31/10	Technical Update
<p>Creep Strength-Enhanced Ferritic Steel Weld Metal for Tempering at Low Temperatures: Post-weld heat-treatment (PWHT) is required for creep-strength-enhanced ferritic steels (CSEF). Current weld consumables for these alloys often require high PWHT temperatures to achieve proper tempering of the weld metal. The variability in field heat-treatment temperature poses a problem in that proper tempering may not occur or the lower critical temperature will be exceeded, both of which will degrade material performance. This study will investigate methods to adjust filler metal compositions to allow for lower-tempering temperatures of CSEF steels to reduce the risk of failures due to improper field PWHT.</p>	12/31/10	Technical Update
<p>Weld Metal & Process Selection Guidelines for Joints at High-Temperature Service: Selecting the proper welding consumable and welding process for joints that will operate at high temperature (in the time-dependent regime) requires considerable engineering judgment. Meeting an ASME Section IX qualification for a given joint will not guarantee adequate lifetime of plant components and could even accelerate damage. This guide will illuminate these issues and provide a framework and recommendations for weld metal selection, joint design, and welding process for welds that will operate at high temperatures.</p>	12/31/10	Technical Update
<p>Welding & Repair Technology for Power Plants: This very successful conference, held jointly with EPRI's Nuclear Sector every two years, focuses on disseminating the state-of-the-art welding and repair technology available for power plants. Highlighted during the conference are repair methods, welding technology, application of weld overlay, corrosion mitigation technologies, materials of construction, and industry experience with application and performance of the various technologies.</p>	08/30/10	Workshop, Training, or Conference
<p>Tempering Parameters for Grade 92: Grade 92 use is increasing in plant construction, yet little data is available on the properties and performance of welded joints subjected to varying tempering heat-treatments. Building on the knowledge gained with P91, a heat-treatment study will be conducted on P92 base metal and welds to develop a tempering parameter for the alloy and limits to ensure proper properties are achieved.</p>	12/31/10	Technical Update
<p>Recommendations for Weld Strength Reduction Factors: This project will recommend procedures, testing, and data requirements necessary to establish Weld Strength Reduction Factors (WSRFs) for use in codes and standards.</p>	12/31/10	Technical Report

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Narrow-Groove GMAW & FCAW for Improved Productivity	12/31/11	Technical Report
Weld Metal & Process Selection Guidelines for Joints at High-Temperature Service	12/31/11	Technical Report
Tempering Parameters for Grade 92	12/31/11	Technical Report

P87.003 Reliability of Materials In Corrosive, Abrasive, and High-Temperature Operation (058207)

Key Research Question

Corrosion in power plant piping, heat exchangers, boiler tubing, and other components costs power companies millions of dollars each year. At high temperatures, oxides growing in steam circuits control many of the failure and damage mechanisms around the plant, including remaining life, solid particle erosion, and short-term overheating. Hot corrosion attack and wastage due to erosion reduce tube life and require coatings, weld overlay, or alternate materials. Additionally, fossil power plants experience a multitude of low-temperature corrosion problems in a variety of plant systems, including raw water and pretreatment systems, cooling water, service water and fire protection systems, condensers, cooling towers, auxiliary heat exchangers, low-pressure feedwater heaters and piping, deaerators, steam turbines, electric generators, air heaters and ducts, flue gas desulfurization systems, and flue gas ducts and stack. Corrosion problems with high cost impact in the fossil power industry will receive highest priority.

Approach

This project addresses corrosion and abrasive damage at both low and high temperatures through the development of a fundamental understanding of these damage mechanisms affecting power plant materials and components. Various coatings, including nanostructured coatings, will be investigated for mitigation of both corrosion and erosion in various components. Modeling of the corrosion process and methodologies to control key industry issues such as exfoliation of stainless steel tubing will be undertaken.

Impact

- Investigate new materials as they are developed and installed in power plants, to understand to oxidation rate, oxide morphology, and eventual exfoliation of the oxide. Temperature effects, as a result of an oxide scale buildup, can have an adverse affect on remaining life, and how the oxide exfoliates can determine if tube pluggage and resulting short-term overheat or turbine solid particle erosion (SPE) damage is a concern.
- Develop improved understanding of high-temperature erosion and corrosion in hard-facing alloys.
- Improve many aspects of power plant equipment condition, including oxidation, corrosion, and erosion resistance, with developments in nanostructured coatings.
- Minimize damage and address all metallurgical aspects of feedwater heater and tube corrosion with project-developed guidance.

How to Apply Results

Results delivered through guidelines, reports, and workshops give members a fundamental understanding of damage mechanisms affecting power plant components. Knowing how oxides exfoliate can assist in determining if tube plugging is likely and in understanding solid particle erosion of turbine blade diaphragms. The guidelines can be integrated into members' processes and procedures to improve operations and reduce damage caused by high-temperature operations.

2010 Products

Product Title & Description	Planned Completion Date	Product Type
Feedwater Heater Failure Manual: Damage in feedwater heaters is one of the more costly low-temperature corrosion issues experienced by utilities. This work will complete a multiyear effort to assemble a feedwater heater failure manual describing materials and damage mechanisms.	12/31/10	Technical Report
Oxidation of High-Chromium Ferritic Steels: Studies have shown the thickness of steam-grown oxides, often used to evaluate metal temperature, are highly dependent on chromium levels between 8 and 12% chrome. Furthermore, sulfur, nickel, and other elements have been found to be beneficial to oxidation rate. Most oxidation studies have been conducted on alloys with ~9% Cr, whereas commercial products have been found to have only ~8% Cr and thus may have much different oxidation rates. This project will assess the effects of chemistry on the oxidation rate and oxide thickness of high-chromium ferritic steels, to improve temperature prediction methods with the additional benefit of improving existing exfoliation models.	12/31/10	Technical Update
Scale Exfoliation Model applied to Fine-Grained Austenitics: A steam-oxidation and exfoliation model has been developed for ferritic steels and austenitic alloys. Further refinement to the model applied to fine-grained austenitics including Super304H and 347HFG will be conducted for assessing new plant and retrofit operation.	12/31/10	Technical Report
Hard coatings for Sootblower or Flyash Erosion Resistance: Continued work investigating the myriad of new hard-facing alloys and hard coatings available for sootblower and flyash erosion. Research will evaluate the corrosion and erosion behavior of these material systems.	12/31/10	Technical Report
Nanostructured Coatings for Improved Oxidation and Erosion Resistance of Valve Materials: Erosion of valve surfaces from exfoliated oxides, and oxidation of valve internals such as stems, reduce steam valve operational reliability and life. Various materials and surface modifications such as nitriding have been used with varying degrees of improvement, but high erosion rates remain. Nanostructured coatings, developed by EPRI's Technology Innovation (TI) program for gas and steam turbine blades, can provide surface hardening with improved oxidation resistance compared to bare metals and standard coatings. This project, performed jointly with Program 65, will identify potential nanostructured coatings, apply them to a valve stem, evaluate the coating integrity, install a coated stem in the field, and monitor its performance.	12/31/10	Technical Update
Coatings to Mitigate SCC in Finned Tubes: Stress corrosion cracking has been identified in the final stage economizers in heat recovery steam generator finned tubes. Tube fouling also has become an operational concern. Coatings that both shed slag and water may eliminate these potential failure mechanisms. This project will work with Program 88 to evaluate a series of coatings for this application.	12/31/10	Technical Update

Future Year Products

Product Title & Description	Planned Completion Date	Product Type
Nanostructured Coatings for Improved Oxidation and Erosion Resistance of Valve Materials	12/31/11	Technical Report
Oxidation of High-chromium Ferritic Steels	12/31/11	Technical Report