Fossil Materials and Repair - Program 87

Program Overview

Program Description

Today's fossil power plants are being tasked with flexible operation by pushing for maximum output during peak price periods, transitioning to low-load and multi-shift operation, and frequent fuel switching to take advantage of spot market opportunities. These practices can accelerate material damage in major power block components. New materials are being introduced for replacement of components in aging plants, in the building of higher-efficiency power plants, and in the construction of components with thinner walls for improved operational flexibility. Regulations on air and water quality have resulted in construction of new pollution control equipment and water management technologies that are more demanding on materials than older vintage systems. Improved knowledge of materials behavior in such environments allows for accurate prediction of remaining life, proper choice of repair strategies, and optimized material selection, fabrication, and repair.

To address these needs, the Electric Power Research Institute's (EPRI's) Fossil Materials and Repair program (Program 87) provides the integrated materials selection guidance, repair and welding technologies, and corrosion mitigation methods to improve equipment performance, reliability, and safety.

Research in this program also supports EPRI's *Near-Zero Emissions* roadmaps with a particular connection to the *Increased Energy Conversion Efficiency* R&D roadmap, through development of high-pressure, high-temperature alloys that can be used in producing advanced ultrasupercritical materials. These materials enable development of new fossil-fueled power plants with much higher combustion efficiencies, resulting in fewer emissions.

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. Improved efficiency and reliability are two reasons for the selection of new materials for retrofit and new-build projects. EPRI's Materials and Chemistry programs provide data on critical material degradation mechanisms, conduct materials and chemistry-related R&D for advanced generation technologies, and quantify the benefits of improvements. These programs help utilities balance the risks and costs of the largest, most costly equipment, and focus on using new 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;
- Minimize, with the goal to eliminate, repeat failures and equipment damage, and reduce outage frequency and duration by using improved knowledge of damage mechanisms and tools for 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;
- Use new and advanced repair technologies; and
- Maximize component life through improved materials selection guidance and procurement specifications.

Approach

Through a continuum of materials and repair guidelines, handbooks, technical projects, and conferences/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.

Accomplishments

EPRI's Fossil Materials and Repair program conducts proactive R&D in all aspects of plant materials performance, repair and welding technology development, and corrosion mitigation. It has:

- Provided industry leadership in addressing fabrication, installation, welding, and degradation of creep-strength-enhanced ferritic steels and advanced austenitic stainless steels
- Developed comprehensive International Steam Boiler and Steam Turbine Metallurgical Guidelines
- Provided guidance on behavior and remaining life of austenitic stainless steel materials used for superheater and reheater tubing applications
- Developed welding guidelines for boiler applications and advanced ferritic and austenitic alloys
- Published a series of metallurgical handbooks (Grade 11, Grade 22, X20, carbon steels, stainless steels, and advanced stainless steels)
- Developed new models for assessing oxide growth and exfoliation
- Provided innovative solutions and new welding consumables for dissimilar metal weld damage repair and advanced steels
- Addressed low-temperature corrosion issues in wet FGD materials selection

Current Year Activities

The program R&D for 2014 will focus on key issues, including the application of small specimen testing for qualitative and quantitative life assessments; simplified tools for assessing tempering behavior; environmental-assisted cracking in creep-strength-enhanced ferritic steels; improved post-weld heat-treatment procedures; steam oxidation of superheaters/reheaters; erosion issues in steam turbine components; and corrosion in environmental control equipment. Key specific efforts are expected to include:

- Application of scoop sampling material database for small-specimen remaining-life assessments
- New web-based tools for tempering and post-weld heat treatment
- Improved post-weld heat treatment guidance for transition geometries
- Stress corrosion cracking in creep-strength-enhanced ferritic steels T23 and 24
- Application of nanocoatings
- Atlas of steam-side oxides and exfoliated scales
- Improved materials selection for flue gas desulfurization system components

Estimated 2014 Program Funding

$3.75M

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Summary of Projects

Project Number	Project Title	Description
P87.001	Fossil Materials and Repair	Integrated materials selection guidance, repair and welding technologies, corrosion mitigation methods, and materials technology transfer through innovative use of technology.

P87.001 Fossil Materials and Repair (1-105250)

Description

The program seeks to improve equipment performance, plant reliability, and safety through improved understanding of materials in power plants. The program evaluates material degradation in current plants, produces guidelines and tools to identify and predict material damage, and develops effective repair and welding strategies for continued operation under market pressures. Research on both replacement of old components and construction of newer plants using new materials is conducted to understand welding, fabrication, and corrosion to improve materials selection guidance, procurement guidelines, and proper fabrication (welding) procedures. New welding technologies, consumables, and processes to improve quality and speed are assessed in lieu of application in a "real-world environment. To most effectively transfer research results to members and improve the knowledge of materials in the industry, the program focuses efforts through a series of tools including reports, briefs, webcasts, workshops, focused meetings, targeted communications, and innovative technology transfer.

Approach

EPRI's Fossil Materials and Repair Program (P87) focuses on all aspects of materials science for the power generation sector. Research is conducted by a team of engineers and scientists with backgrounds in materials science, metallurgy, welding, material and component manufacturing, high-temperature materials degradation and life management, specialist testing, and corrosion. Laboratory capabilities in EPRI's Charlotte facility uniquely position the program to conduct projects in materials science, welding, material aging, simulated field assessments, and specialized testing. Collaborative activities with world experts and premier research facilities enhances the program's value to members. Internal EPRI collaborative work through joint projects with component programs is utilized to maximize expertise and value.

The program conducts projects over a broad range of topical areas for materials in fossil-fired power plants. Materials issues in both high- and low-temperature applications for power steam boilers, heat-recovery steam generators, gas turbine combined-cycle plants, environmental control equipment, and the balance of plant are all considered and prioritized by the program advisors.

EPRI's Fossil Materials and Repair Program conducts a number of projects each year under the following categories:

- State-of-knowledge documents
- Material use guidelines (e.g. procurement guidelines for Grade 91 based on research results)
- Material characterization
- Evaluation of new materials
- Development of tools for improved life assessment
- Welding technology
- Weld repair
- Material damage mechanisms
- Corrosion and environmental compatibility
- Technology transfer

Impact

- Apply comprehensive metallurgical guidelines for boilers and turbines
- Help members evaluate advanced materials entering the market and the components fabricated from them and to select optimum materials for long-term operation
- Provide industry with tools and databases for small specimen testing to improve life assessment and understanding of in-plant material degradation
- Work with industry leaders in addressing creep-strength-enhanced ferritic steels (Grades 91, 92, 122, 23, and 24) and advanced austenitic alloys (347HFG, Super 304H, and HR3C)
- 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
- Provide innovative solutions for Grade 91 welding and repair
- Ensure quality new plant and component performance by using welding, fabrication, and installation guidance when working with OEMs, vendors, and architectural engineering firms
- Apply guidelines for selecting weld metal and processes for the appropriate application
- Conduct cutting-edge research and guidance on steam-side oxidation and exfoliation
- Develop improved understanding of high-temperature erosion and corrosion
- Minimize damage and address all metallurgical aspects of low-temperature corrosion

How to Apply Results

Members receive critical information and tools through an array of technology transfer mechanisms. Standard reports and research projects provide the backbone of research results. The program conducts a highly popular monthly webcast series on emerging issues, recent research, and new technologies, which is recorded for later viewing and is available through the EPRI program cockpit. Face-to-face technology transfer meetings are held mid-year and are combined with supplemental project reviews and international conferences to minimize participant travel. Highly successful conferences on Advances in Materials Technology and Welding and Fabrication (joint with EPRI's nuclear sector) are conducted on multi-year rotations. Workshops on failure investigations and basic materials information are also provided. Members have access to the industry’s first "web-based app," which allows members to get up-to-date information via their smart phone, tablet, or computer on selecting proper weld metals and post-weld heat-treatment conditions for standard and advanced alloys.

Supplemental Projects

Weld Repair of Grade 91 Piping & Components (071850)

Background, Objectives, and New Learning

Grade 91 steel is one of a family of creep-strength-enhanced ferritic steels (CSEF). This steel now is routinely installed in both fossil-fuel-fired and combined-cycle units. Recent in-service experience has demonstrated that cracking can occur in CSEF early in life. The reasons include improper heat treatment of welds and components; design or construction practices that result in local stress concentrations; local operating conditions that are unexpectedly severe due to thermal transients or the presence of system loading; and difficulties associated with dissimilar metal welds.

Project Approach and Summary

This project builds directly on the understanding developed in the life management work. R&D will establish key information on removal of damage and approaches for repair welding. Selected variables and weld processes will be investigated, and test programs will link performance to details of how the repair was carried out. This is important because, in contrast to traditional low-alloy steels that are relatively "user friendly" for repairs, CSEF steels introduce an additional complication: the properties and performance of the base metal are critically dependent on the original composition and the full heat treatment history. This aspect is so important that concerns have arisen that the repairability of steels such as Grade 91 will be limited.

Many possible variations are associated with making these repairs, including condition of the parent; degree of tempering (i.e., hardness); and level of creep damage present in the weld metal, heat-affected zone (HAZ), and parent. This project will address a number of key questions:

- What are the most appropriate methods for material removal, and what should be the extent of the excavation?
- What welding process should be used?
- What is the best method of filler metal selection and optimization of bead sequence and welding parameters?
- Can welds be performed using temper bead welding followed by a minimum PWHT?

Benefits

A recent EPRI project has successfully established the background technology necessary for approaches that ensure high-quality components are supplied and installed. In addition, this work delivered a life-management strategy that is both practical and effective in preventing in-service failures. However, large numbers of current components are susceptible to cracking. In the majority of cases, the defects will need to be repaired using fusion welding. The current project will examine key variables involved in repair decisions and quantify which of these variables has the greatest influence on subsequent performance. This knowledge will permit utilities to minimize the time and costs associated with making a repair while maximizing the potential that the repair will provide at least adequate in-service performance.

Life Management of Boiler and Piping Components Fabricated from Grade 92 Steels (071851)

Background, Objectives, and New Learning

Work to date on Grade 92 steel has demonstrated that this creep-strength-enhanced ferritic (CSEF) steel will be susceptible to many of the problems that have been found in Grade 91. Problems have been identified with incorrectly controlled heat treatment, inadequate quality assurance during fabrication and installation, and Type IV cracking in the heat-affected zone (HAZ) of welds. Additional challenges will significantly influence longer-term damage, including:

- Very-low-ductility creep failure of base metal samples has occurred, which significantly raises concerns over catastrophic fracture, and
- Issues associated with creep failure of welds. It appears that creep failure can occur in the weld metal, depending on the post-weld heat treatment conditions used.

Project Approach and Summary

This project will build directly on the understanding developed in the work performed to date studying the life management of Grade 91 steel. Specifically, work on Grade 92 steel will be undertaken to:

- Establish key information on how the composition and heat treatment of the parent affect microstructure, strength, and ductility;
- Establish links between microstructure and development of damage under service conditions; and
- Examine how key variables associated with weld manufacture influence creep life and in-service failure.

The level of work performed will depend on the participation in the project. The following outline shows key potential issues that can be included. The details of the final scope will be established at the project initiation meeting with the sponsors.

The work will be considered in two complementary tasks:

Task 1: Parent Steel Issues

In addition to heat treatment influences, possible metallurgical issues include N:Al ratio and variation of elements that will influence the presence and extent of ferrite. It is anticipated that at least two parent compositions will be selected, and the samples will be renormalized and then tempered. Potential variables include normalizing temperature, cooling rate, tempering temperature, and time. The tempering conditions will be selected to reflect normal tempering and then a range of over-tempers.

For each condition, optical metallography and hardness testing will be performed. This will lead to a microstructural atlas and a tempering master curve, linking softening to thermal exposure. Selected samples also will be long-term aged to examine the effects of aging in the absence of applied stress and strain. Creep testing will be carried out on selected samples. The testing conditions will be used so that damage is representative of long-term service. Samples will be taken to failure and also interrupted at known life fractions so that the development of damage can be studied. Creep-tested parent samples available from previous work will be examined metallographically.

Task 2: Weld Performance

Thick section welds will be manufactured in the selected parent. It is expected that the welds will be manufactured using at least two different processes. For each process, potential variables include consumables, bead size, sequence, and post weld heat treatment. In each case, for all welds made, characterization will include optical metallography, electron microscopy, hardness testing, measurement of mechanical properties, assessment of creep behavior, quantification of damage development, and assessment of factors affecting fracture.

Benefits

A current EPRI project has successfully established the background technology necessary to underpin significant improvements in approaches for ensuring that high-quality Grade 91 steel components are supplied and installed. This project will deliver a practical life-management strategy for Grade 92 steel, which provides the basis for cost-effectively preventing in-service failures.

Tempering Behavior and Characterization of Grades 23/24 Steels (072742)

Background, Objectives, and New Learning

Grades 23 and 24 increasingly are being used in new construction of supercritical (SC) and ultrasupercritical (USC) steam plants, as well as heat recovery steam generators (HRSGs). Applications include high-temperature tubing, waterwall panels, and thick-section components such as headers. These alloys also have been used for replacement tubing and headers in conventional plants.

Recent service experience with Grades 23 and 24 in waterwall panel construction has revealed that these alloys may be susceptible to stress corrosion cracking, especially in the as-welded state. The causes and mitigating circumstances are not yet well understood, and in the absence of clear guidance, users are employing a range of stress-relief heat treatments in an effort to prevent premature failure of these waterwalls. To reduce the risk of failure, some utilities are specifying a stress-relief heat treatment when using Grades 23 or 24, regardless of the intended application.

Additional research is required to improve the fundamental understanding of these alloys, especially in regard to welding and subsequent post-weld heat-treatment (PWHT) and tempering. Grades 23 and 24 generally have a mixed bainitic and martensitic microstructure; however, EPRI research on Grade 23 has shown that the steel also may contain ferrite, and hardness can vary widely, presumably due to variations in elemental constituents such as carbon. The potential for a wide array of microstructures, coupled with elemental variations, results in a large variation of tempering and PWHT behavior in each alloy family. Critical understanding of microstructure development and heat-treatment response in the heat affected zones (HAZ) of these alloys is needed.

To address these issues, research will be conducted to develop new insight into the fundamental heat-treatment response of Grades 23 and 24. The transformation temperatures will be determined for multiple heats of Grades 23 and 24 across a large range of cooling rates. Additionally, the microstructure constituents and their associated tempering behavior will be determined for the various regions of the heat-affected zone and weld metal. The tempering behavior will be established using mechanical testing techniques and characterized using advanced tools.

The information obtained in these various tasks will provide an accurate portrayal of each alloy's starting microstructure, the response of weldments to tempering, and a concrete basis for further procedure development (if required).

Project Approach and Summary

This research will better define the microstructure constituents present in Grades 23 and 24 in several heats, and determine the effect of variations in key elemental constituents. Additionally, newly developed characterization techniques will be used to determine the phases present in the different heat affected zones and weld metal for each alloy. With this information, a detailed assessment will be made regarding the applicability of stress-relief heat treatment to Grades 23 or 24 weldments.

The project will be conducted in three tasks:

1. **Microstructural Characterization:** This will include the development of a continuous cooling transformation (CCT) diagram and simulation of weld HAZ regions, leading to improved understanding of microstructure development as a function of composition and heat-treatment

2. **Welding & Tempering Response:** Tube-to-tube weldments will be produced and subjected to tempering heat-treatments identified in Task 1. Mechanical testing across a range of temperatures will be conducted.
3. **Procedure Qualification:** Based on the success of Tasks 1 and 2, optimum welding procedure qualifications will be conducted.

Reports will be released following the completion of each task.

Benefits

Understanding Grades 23 and 24 from a more fundamental point of view will provide the following benefits to industry:

- Confidence in using these materials in new construction, with the possibility of defining more stringent composition requirements and/or fabrication requirements to help mitigate cracking and failures, improving safety and reliability.
- Assist in outlining appropriate welding and post-weld heat treatment requirements.
- Aid the industry in developing state-of-the-art welding repair strategies for creepstrength-enhanced ferritic steels.

The proposed research will be applicable for these alloys across a range of component types as these alloys become more widely available in various product forms (including tubing, piping, plate, forgings, castings, etc.). Proper utilization of these alloys also can be beneficial in enabling higher-temperature, more-efficient designs in future power plant construction.

Cracking and Disbonding of Hardfacing Alloys in Combined-Cycle Plant Valves (073512)

Background, Objectives, and New Learning

Hardfacing alloys such as Stellite 6 often are used on the surfaces of valves in high-pressure, high-temperature steam piping systems of heat-recovery steam generators (HRSGs). These surface layers normally are applied to low alloy Grade 22 steels or martensitic Grade 91 steels using welding processes. The resultant structures are complex due to factors such as variations in the local metallurgy, specifics of the welding process and differences in geometry. Service experience has shown that many of these hardfacing layers have failed. These failures typically are characterized by significant cracking and disbonding (liberation) of this hardfacing layer from the valve body and discs. In some cases, these failures have caused damage to screens and high-pressure steam turbine blades.

The objective of this project is to produce a best practice guideline for applying hardfacing alloys to valve bodies and valve components to avoid this failure mechanism. Key variables which will be addressed include the materials of construction (predominately cast and wrought 2.25Cr-1Mo and 9Cr-1Mo steels), the welding process parameters, the use of optimized 'butter layers,' and appropriate heat-treatments.

Currently, there is little consensus on the choice and use of appropriate butter layers applied prior to hardfacing application. The extensive use of C12A (a cast variant of grade 91) in HRSG valves necessitates new learnings about the key differences in microstructure, heat treatment, and welding processes required for these valves compared to traditional chromium-molybdenum steels. Another key variable which needs investigation is the typical heavy cyclic service in which these valves must operate, compared to traditional valves in fossil-fueled power plants. Improved understanding of the cracking mechanism is needed by the industry to avoid repeat failures. Overall, there is a need to identify and control fabrication and welding practices that minimize the likelihood of cracking and disbonding.

Project Approach and Summary

The project will conduct four tasks to accomplish the overall goal of producing a best practice guideline. The project will account for typical operational conditions experienced in cycling HRSGs, but field instrumentation studies to determine specific valve temperature cycles will depend on overall support for the project. The project tasks are:

- **Knowledge gathering:** This task will collect and summarize the existing knowledge on cracking and disbonding with hardfacing alloys through three subtasks:
- **Review of utility HRSG experience.** In this subtask, the original EPRI survey will be followed up with more detailed information on recent field experience. Data on valve manufacturing, design, operating parameters, and cracking/failure events will be obtained.
- **Literature Review.** A review of hardfacing cracking mechanisms reported in the literature will be conducted and the mechanisms of failure will be summarized.
- **Vendor Survey.** Vendors of HRSG valves will be surveyed to determine the typical fabrication practices and quality control measures taken in the production of valves with the specific focus on welding process controls for applying hardfacing alloys and heat-treatment of 91 (wrought and cast) components.
- **Metallurgical Assessment:** Based on the results of Task 1, metallurgical examinations of failed components will be conducted to fully characterize cracking mechanisms, processes utilized, and potential routes for improved component behavior. The project then will conduct welding and heat-treatment trials replicating the field experience and modifications for 'best practices' identified in Task 1. These welds will be characterized and compared to the field findings to optimize the best practices.
- **Modeling**: This task will model the typical geometries and cyclic service of valve bodies to examine the severity of stress and strain encountered in the hardfacing layers. The use of 'butter layers' and dilution will be examined to determine combinations of materials which will minimize stress.
- **Create a best practice guideline:** Utilizing the knowledge gained in Task 1, the metallurgical findings and improved process parameters obtained from the task 2 laboratory work, and the learnings from the task 3 modeling work, a best practice guideline for optimum application of hard facing on valve bodies for HRSG steam systems will be produced

Benefits

This project will provide critical information and guidance to companies operating combined cycle plants. For companies which already have identified disbonding of hardfacing, optimum fabrication practices for replacement components or repair activities will be gained. For those which have not yet experienced disbonding or have not inspected these components, the guideline will provide background of utility experience with poor fabrication practices which can be used to prioritize the need for inspection. Companies planning to construct additional steam systems and combined-cycle plants will have a best practice guideline for future installations. The lessons learned can also be applied to other hardfacing applications in conventional plants.

FGD Absorber Recycle Pump Reliability and Repair Solutions (074463)

Background, Objectives, and New Learning

Flue gas desulfurization (FGD) absorber recycle pumps are not meeting reliability requirements in a number of installations. This leads to increased sulfur dioxide (SO_2) emissions and forced outages. The challenges reported in the industry mainly are in pump liners and mechanical seals. There are several different approaches employing materials and design modifications, but there is a dearth of information to make cost-effective decisions on FGD absorber recycle pump repairs. Comparing material degradation, design parameters, operational practices, and maintenance task effectiveness could yield greater reliability of these pumps, which are critical to the operation of FGD systems.

Project Approach and Summary

This project will use a combination of field observations and controlled testing to investigate solutions to increase pump reliability to a level closer to design assumptions. Using data from a host site, EPRI will work collaboratively to investigate different operational, maintenance, and design practices as possible solutions. This project will include the following four tasks:

1. Site Assessment at Host – EPRI plans to choose at least one host site from among the project participants to perform an independent evaluation of applicable parameters to the performance of the pump and the connected components (inlets, nozzles, absorber tank, etc.) and to evaluate system parameters, focusing on possible causes of accelerated degradation of pump components. This assessment is intended to help diagnose issues and root causes that in turn will help specify the scope of the tasks that follow.

More host sites could be considered, based on project funding and potential technical findings.

2.Evaluation of Mitigation Methods – EPRI plans to use a combination of equipment assessments, member operational data, and laboratory materials testing to collect data on performance of different liner materials (high chrome, silicon carbide, etc.), seal designs, and mitigation techniques.

3. Lifetime Repair Cost Assessment – EPRI plans to develop a cost model to give members a framework to develop repair, refurbishment, and replacement strategies for FGD absorber recycle pumps. EPRI plans to select an variety of options, covering a breadth of approaches.

4. Meetings/Webcasts – EPRI plans to use webcasts as the primary means of updating project members. In conjunction with project participants, EPRI also plans to also host at least two project meetings to collaborate with OEMs and industry professionals to better inform the project output.

Benefits

EPRI members increasingly are compelled by emissions regulations to install and maintain FGD systems to control SO_2 emissions. Absorber recycle pumps are critical to the operation of these systems, directly affect air quality, and frequently cause member utilities greater-than-expected costs. Increasing the reliability of these pumps can decrease emissions and operational costs, benefiting both the plant owners and the general public.

Participants in this study will receive data on the most effective repair and operations strategies for more cost-effective FGD operation and an opportunity to collaborate with peers, OEMs, and experts on solutions.