Overview

Reducing costs and maximizing the productivity of fossil and nuclear generation assets depends on continued innovation in materials science and technology. EPRI is creating new austenitic alloys and advanced manufacturing processes for lower-cost components. In addition, improved understanding of stress corrosion cracking (SCC), environmentally assisted cracking (EAC), creep fatigue, and corrosion fatigue is being developed to enhance management, control, and prevention of these critical damage mechanisms.

Progress and Plans

For several areas of ongoing research, achievements to date and next steps are highlighted below. Additional details on these and other strategic projects are available from the EPRI program manager and from recent publications.

Austenitic Stainless Steels. High-cost nickel-based alloys are currently planned for use in advanced ultrasupercritical (A-USC) coal plant headers and piping operating at 650°C (1200°F) and higher. An austenitic stainless steel material, CF8C-Plus, has been identified as a potentially more durable, less expensive alternative. At present, CF8C-Plus is commercially available only in cast form, necessitating development of additional manufacturing and processing criteria to enable use of lower-cost wrought components for A-USC applications.

In 2009, EPRI and Carpenter Technology Corporation forged a CF8C-Plus ingot, subjected it to various reductions simulating those required to fabricate wrought pipe and headers, and compared its characteristics to those of cast CF8C-Plus and other A-USC nickel-based alloys. Uniform grain structures are 6 to 9 times finer than typical as-cast dendritic structures, resulting in the wrought CF8C-Plus steel being 10 to 15% stronger and having 2 to 6 times better impact resistance at room temperature. Initial mechanical and metallographic testing at elevated temperature indicates that the wrought alloy also offers the potential for excellent performance under A-USC conditions. In particular, wrought CF8C-Plus is approximately 20% stronger than as-cast material at 760°C (1400°F). It also tends to have higher creep rupture ductility, consistent with its significantly refined grain size. Large-diameter CF8C-Plus pipe extrusions will be completed and evaluated during the second half of 2010. Results will be used to develop an ASME Boiler & Pressure Vessel Code Case to qualify wrought components for power plant applications.

Strategic Connections

- New Plant Build
- Long-Term Operation
- Component Life-Cycle Costs
- Capital Costs

Using powder metallurgy methods to manufacture valve bodies and other large, complex components could significantly reduce manufacturing and delivery lead times and costs.
The fabrication of large components may be possible using advanced stainless steels, steel alloys, and nickel-base alloys.

In feasibility testing conducted in conjunction with Carpenter Technology, a valve body was designed and manufactured from 316L stainless steel in near-net-shape form using PM/HIP methods. Ultrasonic testing indicates that the 316L PM/HIP material offers superior inspectability, relative to a conventionally cast stainless steel component, due to its more homogeneous microstructure. Mechanical and metallographic characterization indicates that the new valve body also offers a 10 to 15% improvement in performance. During 2010, EPRI is working with two valve manufacturers and Carpenter Technology to manufacture and test multiple heats of Grade 91 and 316L stainless steel valves. Results will be used to generate an ASME Code Case to permit use of the new manufacturing method for pressure-retaining components.

**Value.** PM/HIP fabrication of large, near-net-shape components represents a potentially transformative technology. Anticipated advantages include improved inspectability, precise control of materials chemistry during manufacture, decreased need for machining, and improved weldability. By significantly increasing materials utilization efficiency, reducing manufacturing and delivery times, and expanding the number of qualified suppliers for nuclear and USC plant components, PM/HIP fabrication could translate to a 30 to 40% cost reduction for critical equipment.

**Advanced Component Manufacturing.** Valve bodies, pump housings, turbine casings, and other large and complex power plant components are commonly fabricated today using casting and forging processes that have been employed for this same purpose since early in the 20th century. Powder metallurgy (PM) methods—including hot isostatic pressing (HIP)—offer a number of potential advantages, and remarkable progress in recent years suggests that cost-effective fabrication of large components may be possible using advanced stainless steels, steel alloys, and nickel-base alloys.

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**SCC and EAC.** The earliest stages of SCC in nickel-based light water reactor (LWR) components remain poorly understood, mainly because they take place over long periods and on extremely small scales that have proven resistant to examination using conventional analytical methods. In strategic work, EPRI is improving basic knowledge of crack initiation and propagation mechanisms based on the use of atomic probe tomography (APT), surface-enhanced raman spectroscopy (SERS), and other techniques. Key partners in this research include EdF and Japanese utilities, government agencies, national laboratories, research institutes, and equipment manufacturers.

In 2009, APT was applied to detect, visualize, and quantify early segregation of individual boron and silicon atoms along grain boundaries, a process linked to increased susceptibility to irradiation-assisted SCC. Also, heterogeneous concentrations of nickel and silicon have been detected and correlated with microstructures associated with localized deformation, and the capability for nano-scale examination just ahead of an advancing crack tip has been demonstrated. Continuing research focuses on APT of alloys in unirradiated, irradiated, and deformed and irradiated condition, taking advantage of this tool’s ability to analyze phenomena occurring at scales that cannot be examined using conventional methods. In addition, synchrotron radiation techniques are being explored to provide the first in situ, X-ray measurements of chemical, structural, and stress/strain conditions.

SERS is being used to characterize the properties of surface oxides on Alloys 600 and 690 in high-temperature water (300 to 320°C; 572 to 608°F). Because these films either block or allow initiation of intergranular SCC under primary water conditions, relations between the surface composition of the base metal and the identity and properties of the resultant
surface oxide are critically important. Recent SERS imaging suggests that electropolishing components may, under some circumstances, change surface composition to increase SCC susceptibility. Ongoing research focuses on how electronic properties, surface treatments, and potential inhibitors such as zinc impact oxide chemistry and behavior.

Factors controlling low-temperature crack propagation (LTCP), a form of hydrogen embrittlement that can severely degrade the fracture resistance of certain nickel-based alloys, also are being examined. In recent research, no reduction in fracture toughness was measured for Alloy 182 weld metal in a simulated boiling water reactor environment under hydrogen water chemistry at 100ºC (212oF). By contrast, a thermally aged sample of CF-8, a cast austenitic stainless steel, showed increased LTCP susceptibility after fatigue precracking in a simulated pressurized water reactor environment under shutdown water chemistry at 54ºC (129oF).

**Value.** Strategic research is providing unprecedented insights into how SCC and EAC damage processes initiate and evolve in different materials and operating environments, improving predictive modeling and informing development of mitigation strategies. For existing plants, this work will support damage prevention and early intervention before life-limiting cracking occurs, help optimize inspection and maintenance schedules, and increase regulatory confidence in Alloy 690 and other replacement materials. Potential unit-specific savings range from millions of dollars on up to the value of the steam generator. For new plants, enhanced understanding will lead to design of advanced alloys offering greater resistance and improved component reliability and safety—benefits that will accrue over the entire lifetime of the asset.

**Creep Fatigue.** Due to its enhanced creep strength, Grade 92 ferritic steel is one of the primary alloys to be employed for piping, header, and superheater applications in supercritical and USC coal plants deployed across the next decade. Limited data are available on its long-term creep-fatigue performance in real-world settings. In 2009, EPRI initiated research in conjunction with Central Research Institute of Electric Power Industry (CRIEPI) in Japan to assess the long-term properties of two Grade 92 welded pipe coupons under cyclic conditions. Results will provide the foundation for improved life management of components manufactured from this alloy.

**Value.** Knowledge of the creep-fatigue behavior of Grade 92 and its weldments is critical for predicting and optimizing component lifetime depending on design and construction parameters, cycling exposure, operating history, and additional factors. Operators will be able to accurately determine when repairs or replacement should be performed to avoid unexpected failures such as those recently seen in Grade 91 components.

**Corrosion Fatigue.** For low-pressure steam turbine blades, crack initiation often begins in corrosion pits subject to high steady and dynamic stresses. While generally understood, the transition from pit to crack is not sufficiently quantified to support accurate remaining life assessment. In a new 2010 project, the conditions underlying this transition are being investigated through accelerated materials testing at BOKU (Austria) and National Physical Laboratories (UK). New knowledge of the corrosion-fatigue damage progression will support development and verification of a remaining life assessment tool addressing pit growth, pit-to-crack transition, and crack growth stages.

**Program Value**

Advanced materials and component manufacturing processes could lead to a significant reduction in the capital and life-cycle costs of high-efficiency coal plants and new nuclear plants, necessary generation options for reducing the electric sector’s carbon emissions. New understanding of major damage mechanisms will help power producers adjust operations and maintenance practices to optimize component lifetimes while avoiding catastrophic failures. It also will support development of methods and materials for mitigating or preventing damage initiation and evolution in both existing and new capacity.
Resources


The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI’s members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI’s principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.