# Advancing Stress Corrosion Cracking Research in Engineered Systems

*Unveiling material degradation to optimize performance*

Pacific Northwest
NATIONAL LABORATORY

Researchers at PNNL discuss a cross section of a specimen mounted in epoxy that is ready for post-test scanning electron microscopy characterization.

**Stress corrosion cracking (SCC)** is prevalent across various industries such as power generation, oil and gas, aerospace, and chemical processing, where components operate under combined mechanical stress and harsh environments. As the most penetrative form of corrosion, it represents one of the most challenging degradation modes, driving substantial maintenance costs, operational downtime, and safety regulations. Improved material selection, advanced monitoring techniques, and predictive maintenance strategies are typical approaches to minimize the life-limiting and financially impactful consequences of SCC.

Pacific Northwest National Laboratory (PNNL) is addressing the need to evaluate SCC across a range of industries through a comprehensive approach that combines decades of expertise and innovative experimental methodologies. PNNL first established its expertise in providing high-fidelity, quantitative crack growth and microstructure data through evaluation of high-temperature SCC in nickel-based alloys and stainless steels used in light water reactor pressure boundary structures. That data is being used to inform reactor inspection requirements. Expanding on this foundation, PNNL has branched into other environments and testing methodologies. Recent highlights include the development of atmospheric SCC test systems to quantify the effect of various mechanical, material, and environmental factors on chloride-induced SCC in support of lifetime management of spent nuclear fuel dry cask storage systems made of 300 series stainless steel and the development of corrosion fatigue life measurements of high-strength martensitic stainless steels in various river water environments, facilitating the design and material selection for hydropower turbine components. PNNL has the expertise to expand SCC testing to molten salt reactor environments in support of research and deployment efforts.

PNNL's approach starts with tailored experimental testing to recreate representative operational environments, enabling the cost-effective generation of high-fidelity, quantitative data on SCC initiation and propagation. Advanced microstructural characterization techniques provide detailed insights into cracking morphology, microstructural interactions, and corrosion product characteristics, while in-depth mechanistic analyses reveal key factors driving SCC, such as stress states, environmental conditions, and material properties. By using this integrated methodology, PNNL delivers actionable solutions to predict materials degradation and mitigate SCC risks, therefore enhancing the reliability of critical infrastructure operating in harsh conditions.

PNNL's core SCC capabilities include:

## STATE-OF-THE-ART SCC TESTING FACILITIES

*PNNL has established one of the largest advanced SCC testing facilities in the world, enabling precise, continuous monitoring of materials degradation under well-controlled environmental and mechanical conditions. Key features include:*

- **Precise environmental control and dynamic adjustment capability** in 21 recirculating SCC test systems on a variety of factors (e.g., corrosive media composition, temperature, dissolved gas content, loading conditions, etc.), to establish representative SCC testing conditions across aqueous (up to 360°C), gaseous, and humid air (up to 95°C) environments.
- **Multi-specimen capacity** in every test system (maximum capacity: 36 specimens in the largest test systems) via serial loading, compatible with various specimen geometries.
- **In situ crack initiation and growth rate** with top-notch resolution (average human hair diameter for crack initiation and 0.03 mm per year for crack propagation).
- **High-stability active load control** for both long-term steady and cyclical loading, enabling in situ monitoring of SCC behavior under realistic loading conditions based on known operational stresses.

A materials scientist examines a test sample in PNNL's SCC research lab, where quantitative measurements are used by the Nuclear Regulatory Commission and nuclear power industry to make informed judgments on the stress corrosion resistance of existing and improved materials, along with the expected safe lifetimes of components made from these materials.

## VERSATILE SPECIMEN DESIGN AND TESTING APPROACH

*PNNL excels in delivering customized SCC testing solutions that blend innovation and cost-efficiency to meet clients' special requirements:*

- **Specimen Design:** PNNL utilizes computer-aided design and finite-element modeling to develop customized, application-specific specimen designs integrated with in situ monitoring capabilities, enabling evaluation of SCC measurements tailored to clients' specific challenges.
- **Specimen Extraction:** PNNL specializes in precisely extracting specimens from small, difficult-to-target regions of real components or mockups—such as heat-affected zones, areas with hot cracks, and compositional dilution zones in dissimilar metal welds—to generate high-quality SCC initiation and crack growth data in these localized regions.
- **In-House Material Procession:** Researchers at PNNL bring extensive knowledge of

conventional and novel steels, alloys, and welds. PNNL has developed in-house heat treating, cold rolling, cold forging, and cold tensile straining to create tailored microstructural variations representative of real components.

- **Diverse Testing Approaches:** Beyond SCC, PNNL also conducts research in corrosion fatigue, multi-specimen creep, and fracture toughness testing, all enhanced by in situ monitoring to track crack initiation and propagation—and all customizable to meet clients' needs.

## MULTI-DISCIPLINARY DRIVEN ANALYSIS

*By leveraging multi-disciplinary expertise, PNNL delivers in-depth data analysis and insights into SCC, enabling a comprehensive understanding of complex material behaviors and degradation mechanisms:*

- **Multi-Scale Microstructural Insights:** PNNL routinely employs advanced microscopy tools—including optical microscopy, electron microscopy, focused ion beam technologies, x-ray diffraction, and atom probe tomography—to study SCC from nanometer-scale precursors to millimeter-long cracks, enabling correlation between microstructural characteristics to macroscopic material behavior.
- **Unraveling SCC Mechanisms:** PNNL is at the forefront of unraveling SCC mechanisms by combining multi-scale microstructural insights with expertise in mechanical engineering, materials science, and corrosion science. This integrated, multi-disciplinary approach reveals the complex interplay between material structure, stress/strain, and environmental factors, offering insights into SCC processes. These findings not only advance fundamental knowledge but also guide the development of improved alloys, optimized mitigation strategies, and predictive tools to ensure material performance and longevity in challenging service environments.

PNNL adopts a rigorous and systematic approach to study environmental degradation of materials, leveraging customized testing capabilities to produce high-quality, reproducible data. This data enhances mechanistic understanding, enabling the development of effective mitigation strategies and proactive degradation planning.

Additionally, PNNL research guides the design of new alloys with improved SCC resistance and facilitates accurate material degradation predictions in realistic service environments. Through these approaches, PNNL supports long-term reliability and performance optimization for engineered systems.

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U.S. DEPARTMENT of ENERGY



August 2025 | PNNL-SA-214760 | EED_3733