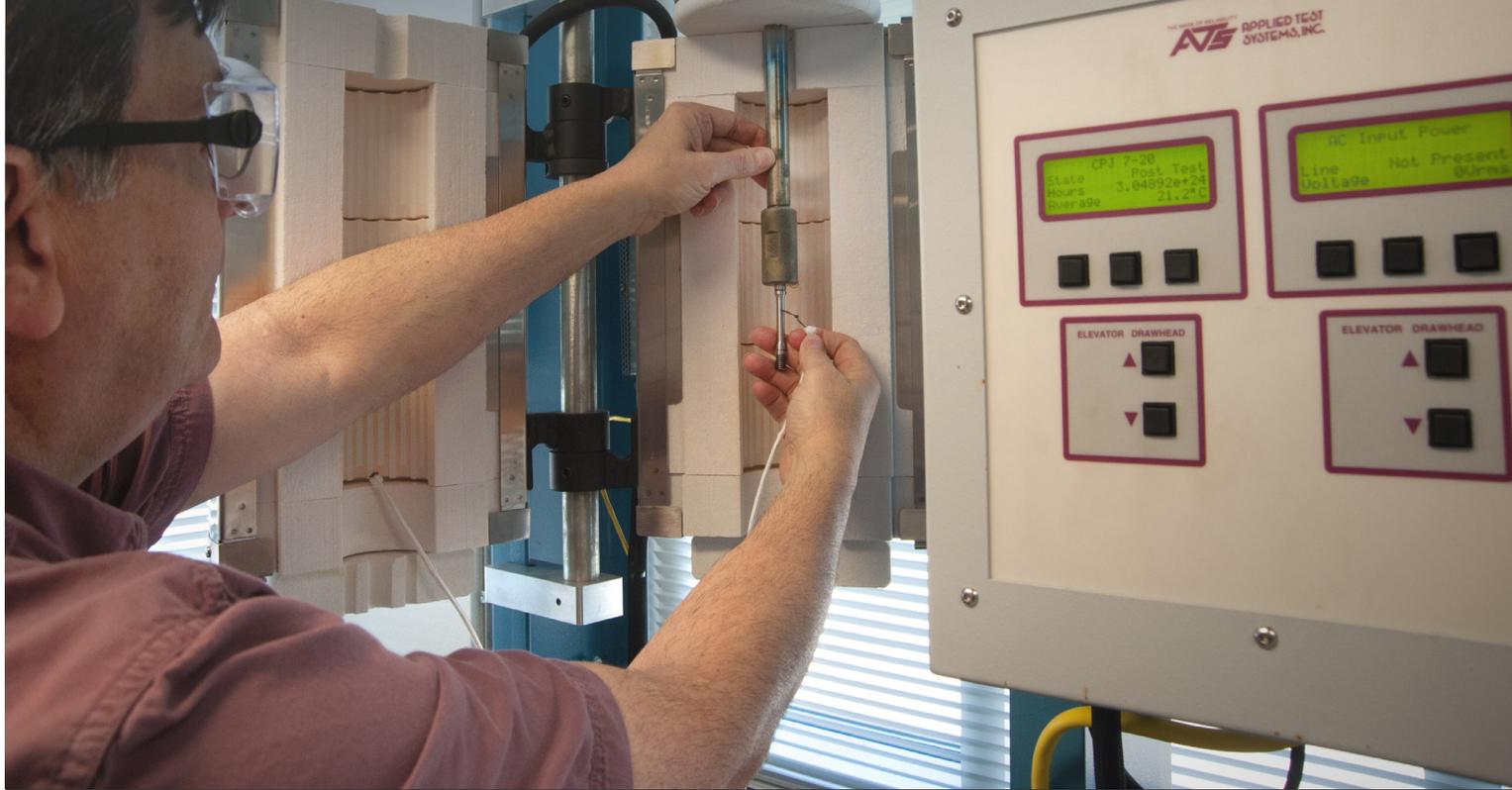


# MATERIALS PERFORMANCE IN HIGH-PRESSURE, HIGH-TEMPERATURE, AND ULTRA-DEEP DRILLING ENVIRONMENTS



# NETL

NATIONAL ENERGY TECHNOLOGY LABORATORY

## BACKGROUND

Oil and natural gas fuel America's economy and account for more than 60 percent of the energy consumed in the United States (U.S.). Most forecasts indicate that these resources will continue to play a vital role in the U.S. energy portfolio for the next several decades. Increasingly, however, the domestic oil and gas industry must search for hydrocarbons in geologically challenging and operationally complex settings, including ultra-deep formations located both onshore and offshore. Innovative exploration and production technologies are needed to effectively and economically access these resources in an environmentally benign way.

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The Department of Energy's (DOE) National Energy Technology Laboratory (NETL) provides expertise and cutting-edge testing capabilities to address the materials performance issues present in deep and ultra-deep well environments. NETL's relevant areas of expertise include:

- Mechanical stability at elevated temperatures and under variable stress states
- Corrosion, corrosion-fatigue, and stress-corrosion interactions
- Microstructural stability under load and at temperature
- Life prediction based on environmental and loading history

NETL's recent research activities have focused on establishing the potential for precipitation-strengthened nickel superalloys to be used for oil and gas components. Experimental research has focused on trying to better understand alloy performance for use in deep and ultra-deep wells where temperature and/or sour environment may be an issue. Researchers examined the change in strength and ductility, with respect to the well environment and the borehole temperature, by looking at fracture toughness and fatigue crack growth rates. In particular, researchers identified the alloys' change in crack growth rate and mode of fracture in deep well conditions as a function of borehole conditions. A better understanding of the alloys' mechanical behavior will enable scientists to more clearly define the alloys' possible role in the oil and gas industry of the future where exceptional corrosion resistance and high strength will be needed.

NETL researchers are also investigating the combined interaction of casing, cement, and lithography on wellbore stability. This research includes the development of experimental testing methodologies to better understand wellbore system response to global and local environments.

## PRIMARY PROJECT GOAL

The harsh environments of ultra-deep drilling wells pose significant challenges for the materials used in drilling and subsequent production activities. The service life of these materials is compromised by high temperatures (up to 500 °F), high pressures (reaching 30 ksi), corrosive species (chloride [Cl<sup>-</sup>], hydrogen sulfide [H<sub>2</sub>S]), and the various complex stress states brought on by extreme pipe lengths and variability in loads of the drill string.

The goal of this project is to evaluate alloy capability for ultra-deep well environments (i.e., drilling, completion, and production activities) and the alloys' potential long-term stability in these environments. By understanding the environmental and mechanical factors that affect performance and influence effective materials life, catastrophic events can be reduced or eliminated.

## OBJECTIVES

The objectives of this project include:

1. To improve the understanding of how deep and ultra-deep well environments influence mechanical behavior and affect the service life of a wide range of materials
2. To identify cost-effective mitigation strategies to eliminate premature failure of critical components
3. To develop new laboratory testing methodologies that utilize time efficient and accurate electrochemical techniques to interrogate materials performance and behavior in simulated high pressure and high temperature (HPHT) environment.

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## PROJECT DESCRIPTION

Materials failures are a concern for the HPHT sour environments encountered in deep well drilling, completion, and production operations. The pressure (reaching 30 ksi), temperature (up to 500 °F), and corrosive substances (>5 ppm H<sub>2</sub>S) in the wellbore environment can result in general corrosion, stress corrosion cracking, sulfide stress cracking, pitting corrosion, corrosion-assisted fatigue failures, and significant wear on components. Consequently, alloys used in these applications must have high-yield strength, excellent fatigue capability, and excellent toughness, as well as good-to-excellent corrosion resistance. In drilling operations, alloys must also exhibit very good wear resistance. To evaluate alloys for use in these extreme environments, the relationships between metallurgical factors and microstructure must be understood, especially in the presence of corrosive species that degrade material integrity.

## CAPABILITIES

NETL has unique capabilities in performing corrosion/electrochemistry, fatigue, and corrosion fatigue testing in environments that can closely simulate sweet-to-sour conditions in deep and ultra-deep well environments. Autoclave facilities are also available that allow a certain degree of control over temperature and pressure for evaluating the electro-chemistry of constituent fluids, as well as long-term exposure studies. Researchers use NETL's microscopy to examine the morphology of cracked samples (scanning electron microscopy) as well as material-environment interaction through chemical evaluation of the corrosion products (energy and wave-length dispersive spectroscopy) left behind at the conclusion of the test. Transmission electron microscopy allows researchers to examine a material at the nanometer level and assess processing modifications to a material's chemical composition or processing history to change its corrosion/electrochemistry behavior, fatigue response, or both.

## BENEFITS

Laboratory tests performed in conditions that simulate service environments are required to better understand mechanisms that cause catastrophic failures of the components in service. The results of NETL's various research projects serve as guidelines for materials testing and selection criteria in the development of tubular materials for the oil and natural gas industry, ultimately allowing safer operations. The results can also be used to identify requirements for new materials with superior resistance to corrosion fatigue, specifically where carbon dioxide and hydrogen sulfide (H<sub>2</sub>S) may complicate the electrochemical interaction between metal and environment solution and, specifically, in the wellbore where cement and lithography have not been taken into account.

Results on fatigue testing of drill string and riser alloys guide design engineers in the use of various alloys for these well conditions. In particular, drilling results of developmental drill pipe UD-165, after exposure to completion fluids containing calcium chloride, will be especially useful because this is one of the highest-strength steels available for use in ultra-deep operations.

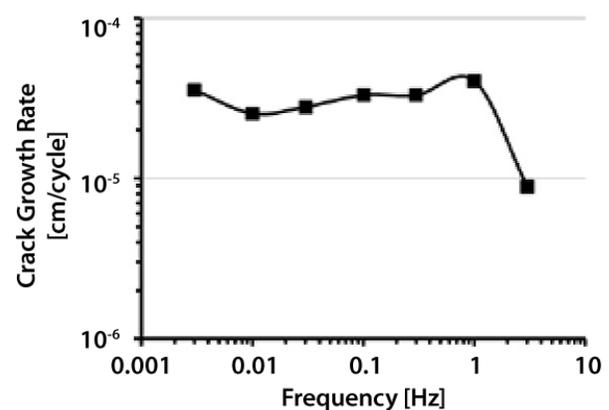


Figure 1. Fatigue crack growth rate.

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## ACCOMPLISHMENTS

NETL's research has focused on identifying gaps in the performance capabilities of high-strength steels and nickel superalloys in deep and ultra-deep HPHT well environments where conditions are generally more severe. NETL's research team also conducted research that provided insights on these alloys' fundamental mechanisms of corrosion and fatigue performance in HPHT environments.

The research included the following accomplishments:

- Investigated the fatigue behavior of high-strength steels for the next generation of ultra-deepwater risers (large-diameter pipes that extend from the wellbore to the surface)
- Examined the impact of surface modification (hammer peening and low-plasticity burnishing) as a means to improve the corrosion and fatigue performance of high-strength steel and nickel superalloys, especially for application in failure-prone component locations
- Provided information on the effect of environmental (temperature, aqueous speciation, pH) factors and the impact of localized corrosion (pitting and crevice corrosion) on fatigue crack initiation and propagation in drill string alloys

- Utilized time-efficient and accurate electrochemical methods to investigate corrosion behavior of alloys in simulated sour service environments as functions of pH, temperature, and H<sub>2</sub>S concentration and determined the role of H<sub>2</sub>S as a catalyst on the corrosion-degradation process
- Developed reference electrodes for use in HPHT systems that have potential as real-time corrosion sensors for down-hole application

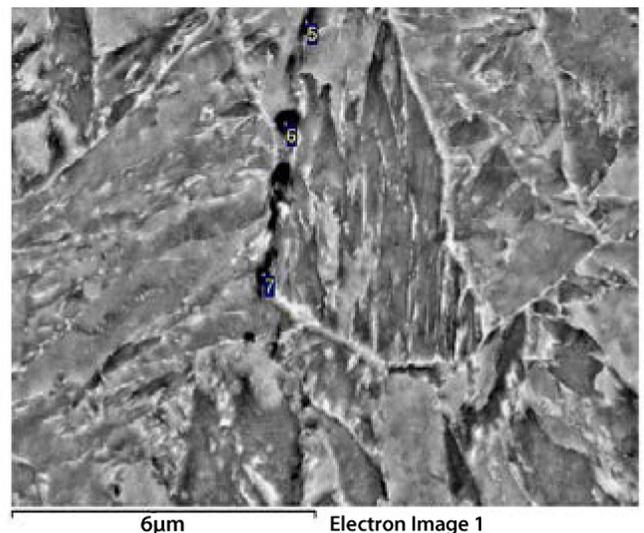


Figure 2. Electron image of crack.

## Research Partner

West Virginia University

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