the ENERGY lab

R&D FACTS

Oil & Gas

Materials Performance in High Pressure, High Temperature (HPHT) Ultra-Deep Drilling Environments

Background

Oil and natural gas fuel America's economy—accounting 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, both onshore and offshore. Innovative exploration and production technologies are needed to effectively and economically access these resources in an environmentally benign way.

The 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

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

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NETL is also engaged in research focused on 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

Ultra-deep drilling environments characteristic of Materials Performance in High Pressure, High Temperature (HPHT) sour 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 (Cl-, H2S), and the various complex stress states due to the extreme pipe lengths and variability in loads of the drill string on the one hand and need for long-term strength and corrosion resistance on the other. In combination, these factors can result in more frequent replacement of materials and increased drilling costs as well as premature failure related to the ultra-deep well stress states, temperature, and corrosion species.

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

Objectives

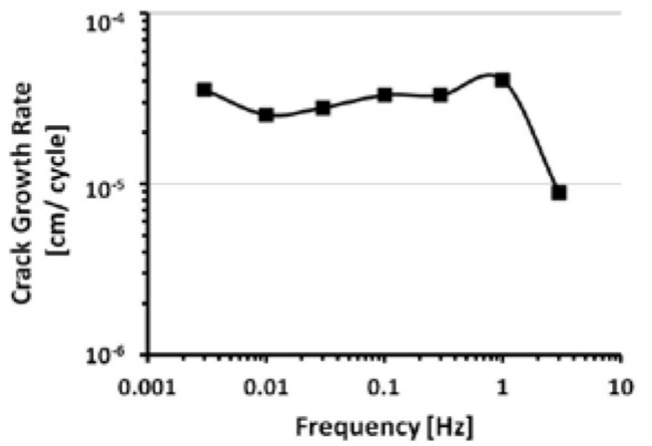
- **Objective 1** - To improve the understanding of how deep and ultra-deep well environments influence mechanical behavior and affect the service life of a wide range of materials
- **Objective 2** - To identify cost-effective mitigation strategies to eliminate premature failure of critical components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

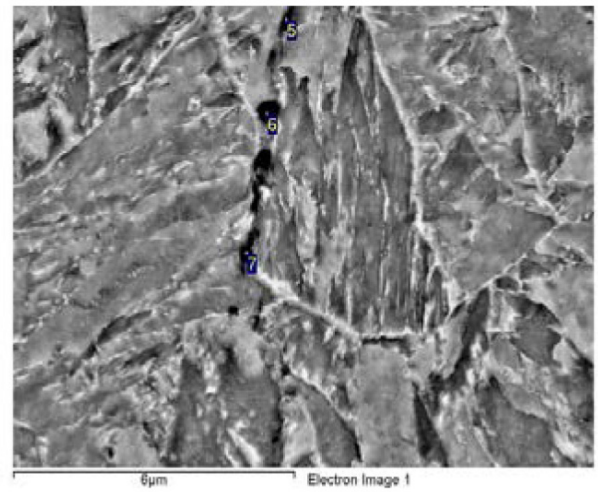
Project Description

Materials failures are a concern associated with 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_2S) in the wellbore environment can result in general corrosion, stress corrosion cracking (SCC), sulfide stress cracking (SSC), pitting corrosion, corrosion assisted fatigue failures, and significant wear on components. Consequently, alloys utilized in these applications must have high-yield strength, excellent fatigue capability, and excellent toughness, with good-to-excellent corrosion resistance, and in drilling operation, very good wear resistance. In order to evaluate alloys for use in these extreme environments, it is critical to understand the relationships between metallurgical factors and microstructure, especially in the presence of corrosive species that act to 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, that allow a certain degree of control over temperature and pressure for evaluating the electrochemistry of constituent fluids, as well as long-term exposure studies, are also available. Microscopy facilities are available to examine the morphology of cracked samples (scanning electron microscopy [SEM]) as well as material-environment interaction through chemical evaluation of the corrosion products (energy and wavelength dispersive spectroscopy [EDS and WDS]) left behind at the conclusion of the test. Transmission electron microscopy provides the means to examine changes to a material at the nanometer level and provides the means to assess processing modifications to a material's chemical composition or processing history in order to change its corrosion/electrochemistry behavior, fatigue response, or both.





Benefits

Performing laboratory tests in the conditions that simulate service environments is required to better understand mechanisms of potential catastrophic failures of the components in service. The results of the various NETL research projects serve as guidelines for materials testing and selection criteria in the development of tubular materials for the oil and natural gas industry so that it can more efficiently operate in a safe manner. The results can also be used to identify requirements for new materials with superior resistance to corrosion fatigue, specifically where CO_2 and H_2S 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 provide information to guide design engineers in the use of various alloys for these well conditions. In particular, the results of developmental drill pipe UD-165 in drilling, after exposure to $CaCl_2$ containing completion fluids, will be especially useful, as this is one of the highest-strength steels available for use in ultra-deep operations.

Accomplishments

NETL's research has focused on identifying gaps in materials 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 the fundamental mechanisms of corrosion and fatigue performance of these alloys in HPHT environments.

Among the research accomplishments:

- Investigated the fatigue behavior of high strength steels for the next generation of ultra-deepwater risers (large-diameter pipes that extends from the wellbore to the surface)
- Investigated the impact surface modification (hammer peening and low plasticity burnishing [LPB]) as a means to improve 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_2S concentration. Determined the role of H_2S as a catalyst on the corrosion degradation process
- Developed reference electrodes for use in HPHT systems that have potential for application as real-time corrosion sensors for down hole applications