the ENERGY lab

R&D FACTS

Oil & Gas

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

Background

Accounting for more than 60 percent of the energy consumed in the United States, oil and natural gas fuel America's economy. 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.

In accordance with the Energy Policy Act of 2005, the National Energy Technology Laboratory (NETL) is working with U.S. industry in a complementary research program designed to develop and demonstrate oil and natural gas drilling and production methodologies in ultra-deep formations. This research intends to address the materials performance gaps that currently significantly limit the reliability and affordability of drilling, completion, and production in these ultra-deep environments.

To further this research, NETL is providing expertise and cutting-edge testing capabilities to address the materials performance issues present in ultra-deep drilling environments. NETL's relevant areas of expertise include:

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

NETL researchers have also explored controlling alloy composition, heat treatment, and surface modification to suppress cracking in a corrosive environment at elevated temperature and high pressure. NETL's understanding of these factors is critical to developing relationships among metallurgical factors, microstructure, and performance in order to develop or identify alloys for use in extreme environments.

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U.S. DEPARTMENT OF ENERGY

In addition, NETL has looked at fatigue behavior of advanced alloys for the next generation of ultra-deepwater risers (large-diameter pipes that extends from the wellbore to the surface). This new generation of risers must withstand increased tensile loads due to wave/current action (in the Gulf of Mexico, for example) as well as internal pressures resulting from drilling into deep formations below the seabed at water depths greater than 10,000 feet. Further, the riser materials must also be able to withstand the ultra-deep environment associated with the combination of seawater (chlorides), air (partial pressure oxygen content), and hydrogen sulfide (H_2S).

While several suppliers of tubular materials have developed ultra-high strength tubes that may enable the design of lightweight risers critical for deepwater applications, information is lacking on the fatigue performance (the fatigue limit, in particular) of these new materials in typical ultra-deep environments. NETL developed fatigue life curves at the appropriate stress conditions for these alloys in order to more appropriately address the fatigue design of the new generation of riser alloys.

In all aspects of drilling, completion, and production, corrosion fatigue is an issue that crosscuts both onshore and offshore operations. However, there is very little information available on the corrosion-fatigue performance of current and potentially new materials at elevated temperature and pressures on the ultra-deep well environment.

Primary Project Goal

Ultra-deep drilling environments pose significant challenges for the materials used in drilling. The service life of these materials is compromised by high temperatures (> 500 °F), high pressures (> 30,000 psi), corrosive substances, and complex states of stress resulting from a combination of extreme lengths and variability in loads of the drill string. In combination, these factors can result in more frequent replacement of materials and increased drilling costs.

The goal of this project is to evaluate alloy capability for ultra-deep well environments (i.e., drilling, completion, and production activities). 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 industry understanding of how the ultra-deep drilling environment affects the service life of materials

Objective 2 - To enable industry to develop cost-effective mitigation strategies to eliminate premature failure of critical components

Objective 3 - To develop new laboratory testing methodologies that utilize electrochemical techniques in simulated high-pressure, high-temperature (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 (> 30 ksi), temperature (> 500F), and corrosive substances (> 5 ppm H_2S) in the well environment can result in general corrosion, stress corrosion cracking (SCC), sulfide stress cracking (SSC), pitting corrosion, 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, in conjunction with Regional University Alliance (RUA) partners and research collaborators, 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. In particular, systems are in place to test smooth bar and single edge notch beam fatigue specimens in an environmental cell with recirculating fluid. Autoclave facilities, that allow a certain degree of control over temperature and pressure for evaluating the electrochemistry of constituent fluids, for example, as well as long term exposure studies, are also available. NETL-RUA has access to a wide range of mechanical testing facilities, most at room and elevated temperatures (but in air) for quasi-static and dynamic testing. NETL also has an environmental chamber that allows limited testing at high pressure and temperatures up to a few of hundred degrees Centigrade. Microscopy facilities are available to examine the morphology of cracked samples (SEM) as well as material-environment interaction through chemical evaluation of the corrosion products (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, its fatigue response, or both.

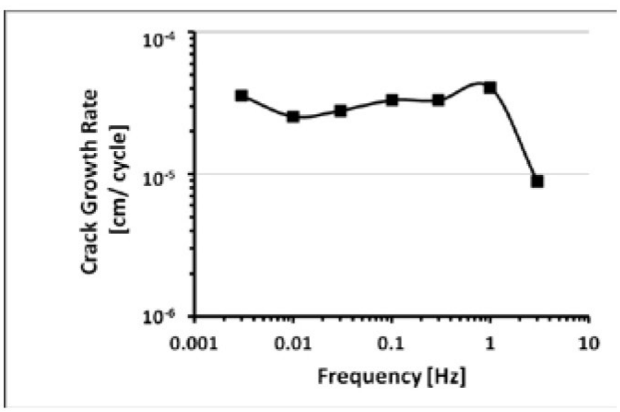
Benefits

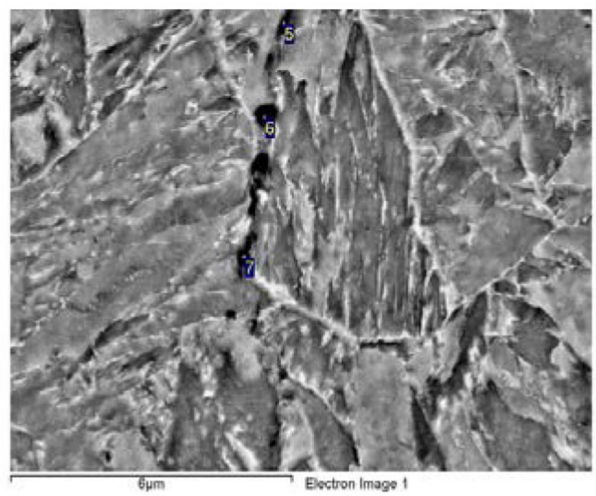
Performing laboratory tests in the conditions that simulate service environments is required to better understand mechanisms of potential catastrophic failures of the components in service. The results of the various research projects in the Ultra-Deep Drilling (UDD) Program will serve as guidelines for materials testing and selection and development for the oil and natural gas industry to operate safely and efficiently under UDD sour conditions. The results can also be used for identifying requirements for new materials with superior resistance to corrosion fatigue, especially where CO_2 and H_2S might complicate the corrosion process.

Results on fatigue testing of drill string alloys will provide the oil and gas industry with information to guide the use of various alloys. 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 UDD operations.

During FY10-FY11 the research focus shifted to understanding the mechanism of corrosion fatigue of high- and ultra-high strength, low alloy steels in simulated sour HPHT conditions. Specifically, the effect that environmental factors had on crack propagation kinetics became important to understand in fundamental terms. In FY12, the research activity has been expanded so that the role of hydrogen in this stress assisted cracking was investigated.

In FY13, the HPHT project will focus on several new activities. One such activity follows from work done at West Virginia University on the effect of hammer peening on corrosion and fatigue. Building upon this effort, new work will focus on the effect of Low Plasticity Burnishing (LPB) on the fatigue strength and corrosion behavior of high strength, low alloy steel and nickel-based tubular (e.g., oil grade 718) used in all deep well drilling activities. It is hoped that by targeting critical areas of tubular joints, or critical areas in the downhole assembly, that performance in sour environments can be improved.





Accomplishments

During FY08, the focus of the project was to identify gaps in materials performance capabilities at HPHT conditions for onshore drilling applications, where drilling conditions are generally more severe than for offshore. For commercial materials, the research team identified sulfide stress cracking, corrosion fatigue, and stress corrosion cracking as potential materials issues.

The FY09 focus was to understand failures in HPHT environments and, in particular, fatigue failures initiated by corrosion, such as pitting. Research focused on understanding the effect of localized corrosion, such as pitting and crevice corrosion, on fatigue crack initiation in drill string alloys.

Another area of research for FY13 will focus on catalytic properties of H_2S. As such, electrochemical corrosion investigations will be conducted on high- and ultra-high strength, low alloy steels in simulated sour service environments as functions of pH, temperature and H_2S concentration. The role of H_2S as a catalyst in each alloy's corrosion degradation process will be determined, and as such, effective means of corrosion control may be forthcoming, such as H_2S scavengers or corrosion coatings.

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