

# METAL-BASED SYSTEMS FOR USE IN EXTREME ENVIRONMENTS

## BACKGROUND

Extreme offshore hydrocarbon operations require strong, durable, and corrosion-resistant materials. Unfortunately, materials currently used in offshore oil and natural gas operations, tubulars for all operations and associated blowout preventer (BOP) components, have reached their limit of effectiveness in terms of operating environment. New materials must be designed to compensate for these shortcomings.

## PROJECT GOAL

The goal of this project is to identify environmental and mechanical factors that affect metal performance in extreme offshore environments. Initial work has focused on wellbore related environments; however, future research may address materials performance on the seafloor and in coastal marine settings, deep offshore, and Arctic areas. It is important to understand which materials are suitable for near-term and immediate use, as well as long-term (decades) performance and legacy-related challenges.

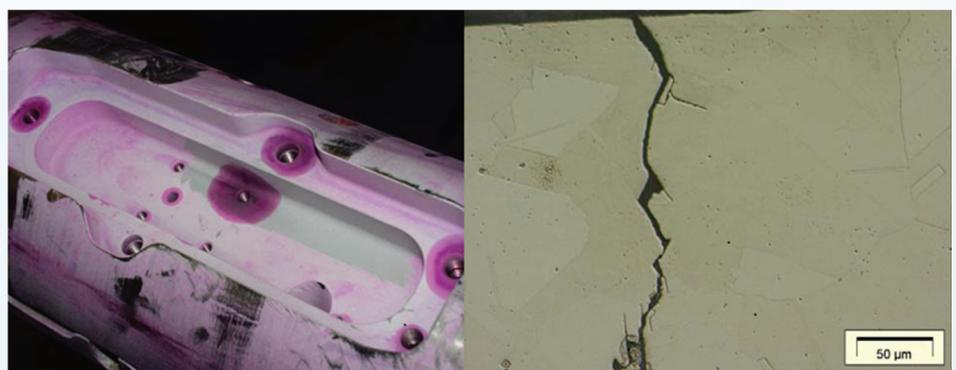


Figure 1. Corrosion Fatigue of Control Sub Made of Alloy 718.

# NETL

NATIONAL ENERGY TECHNOLOGY LABORATORY

## OBJECTIVE

The objective of this work is to evaluate the most commonly used alloys in these applications to characterize their limitations and appropriate uses. Additionally, novel surface treatments that may improve metallic component performance in extreme conditions will be evaluated.

Metallic components are used in risers, umbilicals, drill pipes, pipelines, blow out preventers, and numerous other components associated with offshore drilling in both the water column and subsurface systems. Ensuring the lasting performance and the appropriate use of these materials is a vital step in addressing the economic, environmental, and safety concerns related to efficient offshore production and risk prevention. The development of material information databases to catalogue and analyze baseline physical and mechanical behavior, as well as environment specific property performance, of basic materials is an important element of this project.

# METAL-BASED SYSTEMS FOR USE IN EXTREME ENVIRONMENTS

## PROJECT DESCRIPTION

This project seeks to identify the failure mechanisms and rates of material degradation for critical components in offshore drilling by basing determinations on observed/reported behavior in the field. However, as there is limited publicly available data on the performance of these materials under extreme offshore conditions, the study will be augmented with experimental research on materials performance under simulated extreme conditions. To date, this study has successfully evaluated the strength/corrosion potential of the most common alloys used in extreme offshore drilling under in situ conditions (pressure, temperature, hydrogen sulfide, etc.). Work is ongoing in the development of a pit/fatigue model for the assessment of catastrophic failure potential of these metallic components. The U.S. Department of Energy's National Energy Technology Laboratory is also evaluating new alloys (e.g., nickel-based alloys as a structural material or as a cladding onto steel) and surface treatments (e.g., hammer peening) for ultra-deep well environments. These findings are presented in the document, *Fatigue Crack Growth Rate of UD-165 in Sour Environments*.



Figure 2. The most commonly used alloys in offshore drilling operations are being evaluated in NETL metal corrosion studies.

## NETL CAPABILITIES

NETL possesses a fully equipped mechanical testing laboratory that allows material properties to be determined at room and elevated temperature. Equipment includes electro-mechanical test machines as well as servo-hydraulic test machines. In particular, NETL has looked at high strength, low alloy steels, nickel superalloys, etc., under tensile (and fracture toughness) and fatigue loading conditions (high and low cycle fatigue and fatigue crack growth rate).

NETL also possesses a fully functional metallographic laboratory for preparing samples for light optical microscopy using a variety of viewing conditions. A suite of hardness testers is also available for looking at microstructure changes over small areas.

### Contacts

**Jeff Hawk**  
Principal Investigator  
Research Materials Engineer  
jeffrey.hawk@netl.doe.gov

**Marisa Arnold-Stuart**  
Supervisor, Structural Materials Team  
Materials Engineering & Manufacturing Directorate  
marisa.arnold@netl.doe.gov

Fully functional Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), and microprobe analytical equipment are available for characterizing the bulk and surfaces of materials.

High pressure high temperature (HPHT) autoclaves are used for exposing materials to a variety of environmental conditions similar to those in offshore and deep wells. Coming on-line is an electrochemical reaction autoclave (ERAC) for carrying out electrochemical experiments in simulated offshore production fluids. These experiments will provide corrosion parameters measured in situ to be used for evaluating corrosion resistance of the material investigated in real time. Also, electrochemical test equipment, which includes electrochemical cells, electrodes, and potentiostats/galvanostats, is available for carrying out in situ corrosion experiments in aqueous environments under ambient pressure and elevated temperature.

## BENEFITS

Successful completion of this work will reduce the relative risks for critical components in offshore environments by using data analytics and other large data strategies to determine expected materials lifespan under different operating scenarios.

## ACCOMPLISHMENTS

The fatigue crack growth rate and fracture toughness of ultra-high strength steel (UD-165) and several nickel superalloys (IN 718, IN 625, IN 725) have been determined under offshore, deep-well environmental conditions. The effect of surface modification (e.g., hammer peening) has been investigated for IN 718 in aggressive environmental conditions.

For high-strength, low-alloy steels (HSLA), there must be a carefully determined balance struck between environmental corrosion and critical mechanical properties (fracture toughness, fatigue strength, crack growth rate, etc.). For precipitation strengthened nickel superalloys (which have better corrosion resistance than HSLA steel), the toughness and crack growth resistance must be gauged, as the performance properties in offshore deep-well environments remains relatively unknown. Preliminary research showed Oil Grade 718 to have problems with toughness in some environments. Near-term research will focus on developing an open-database of metal materials performance data for offshore oil and gas operations. To date, this project has focused primarily on materials associated with offshore drilling and production. Consolidation of existing data, as well as targeted specific testing, will illuminate the effect of offshore deep-well environment variables on mechanical behavior and offer strategies to ameliorate performance deficits through other means (such as surface modification, coatings, etc.) without negatively impacting mechanical behavior.

For additional information, we invite you to visit  
<https://edx.netl.doe.gov/offshore>