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Effect of Stress Intensity Factor on Fatigue Crack Morphology in High-Strength Steels in Sour Environments

M. Ziomek-Moroz[a], J.A. Hawk[a], W. Collins[a]
[a]U.S. Department of Energy
National Energy Technology Laboratory
1450 Queen Avenue SW, Albany, OR 97321, USA

R. Thodla[b], F. Gui[b]
[b]DNV-Columbus
5777Frantz Road
Dublin, OH-433017Park, PA 16802, USA

The Unites States predicted a significant growth in energy demand by 2030 makes oil and natural gas primary target fuels for energy generation.[1] The peak of oil production from shallow wells (< 5000 m) is about to be reached and has pushed exploration for oil and natural gas into deeper reservoirs. However, drilling to depths greater than 5000 m requires increasing the strength-to weight ratio of the drill pipe materials. Grade UD-165 is one of the ultra- high yield strength carbon steels developed for ultra deep drilling (UDD) activities.

Drilling UDD wells exposes the drill pipes to Cl^-, HCO_3^-/CO_3^{2-}, and H_2S-containig corrosive environments (i.e., sour environments) at higher pressures and temperatures compared to those found in conventional wells. Approximately 75% of all drill string failures are caused by fatigue or corrosion fatigue[2]. To avoid catastrophic failures of drill string candidate alloys, NETL in collaboration with DNV, has been conducting research on the fatigue crack growth (FCGR) behavior of the ultra- high yield strength carbon steels, e.g., grade UD-165, which was developed for ultra deep drilling (UDD) operations in sour well environments.[3]

The FCGR behavior of ultrahigh -strength carbon steel, grade UD-165, was investigated by monitoring crack growth rate in deaerated 5%NaCl solution buffered with $NaHCO_3/Na_2CO_3$ and in contact with H_2S. The partial pressure of H_2S (p_{H2S}) was 0.83 kPa and pH of the solution was 7. The fatigue experiments were performed on ½T-CT specimens at 20°C at a stress ratio (R) of 0.13 and stress intensity factors (ΔK) of 219.8 and 153.5 MPa√cm, respectively, in an autoclave with surface investigations augmented by scanning electron microscopy (SEM), elemental x-ray mapping and energy dispersive x-ray (EDX) spectroscopy. Research focused on understanding the influence of environment on crack growth rate by examining the crack path in exposed specimens.

Samples in this study failed catastrophically along the crack after they were removed from the autoclave. Figure 1 shows a secondary (SE) SEM micrograph of the fracture surface after the FCGR testing at ΔK=219.8 MPa√cm. It appears that the failure mode is transgranular. Also, few pits are observed on the fracture surface.

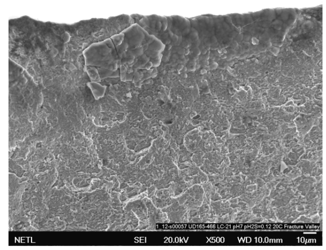

Fig. 1. Microfractograph of UD-165 after a fatigue test at ΔK=219.8 MPa√cm in $NaCl/NaHCO_3/Na_2CO_3/p_{H2S}$ = 0.83 kPa at 20°C, pH=7.

The micrograph of the fracture surface sample after the fatigue test at ΔK=153.5 MPa√cm under sour conditions with pH=7 at 20°C, Fig. 2, looks different from that surface tested at ΔK=219.8 MPa√cm in the same solution.

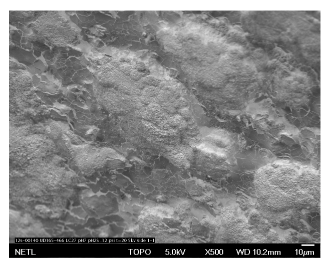

Fig. 2. Microfractograph of UD-165 after a fatigue test at ΔK=153.5MPai√cm in $NaCl/NaHCO_3/Na_2CO_3/p_{H2S}$ = 0.83 kPa at 20°C, pH=7.

Relatively dense corrosion products covered relatively large areas of the sample. Around these crystalline-like structure is observed. The latter is characteristic of intergranular failure.

It appears that at 219.8 MPa√cm , fracture is mainly transgranular, while at 154.5MPa√cm an intergranular fracture is the primary mode of failure.

References:
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