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Effect of Sour Environments on Corrosion Fatigue Crack Propagation in Advanced Drilling Steel

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The Unites States predicted 60% growth in energy demand by 2030 makes oil and natural gas primary target fuels for energy generation.[1] The fact that the peak of oil production from shallow wells (< 5000 m) is about to be reached has, therefore, 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]. Since there is no literature data on the corrosion fatigue performance of UD-165 in sour environments as functions of pH, temperature or H_2S partial pressure research was initiated to better clarify the fatigue crack growth (FCGR) behavior of this alloy in UDD environments.[3,4]

The FCGR behavior of ultra-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 or 9. The fatigue experiments were performed at 85°C in an autoclave with surface investigations augmented by scanning electron microscopy (SEM), elemental x-ray mapping and energy dispersive x-ray (EDX) spectroscopy. In this study, research focused on surface analyses supported by fatigue crack growth rate measurements. Figure 1 shows a backscattered (BSE) SEM micrograph of the crack that propagated from the notch in the solution with pH=7 at 85°C. Accumulation of corrosion products is visible along the crack. Some spallation of the passive layer is observed on the surface. The EDX chemical analysis near the crack tip found iron, oxygen and traces of sulfur and carbon in the passive layer.

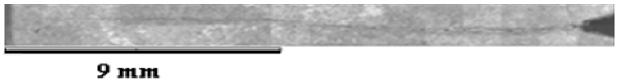

Fig. 1. BSE micrograph of UD-165 after a fatigue test in $NaCl/NaHCO_3/Na_2CO_3/p_{H2S}$ = 0.83 kPa at 85°C, pH=7.

The surface of the sample after the fatigue test in the sour environment with pH=9 at 85°C, Fig. 2, looks slightly different from that fatigued surface in the solution with pH=7 at 85°C.

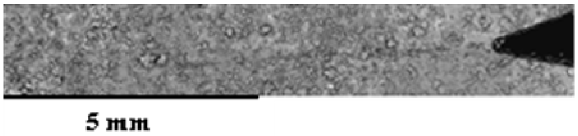

Fig. 2. BSE micrograph of UD-165 after a fatigue test in $NaCl/NaHCO_3/Na_2CO_3/p_{H2S}$ = 0.83 kPa at 85°C, pH=9.

The crack propagates across the passive film that covers the surface fairly uniformly. No spallation of the passive film is observed along the crack or near the notch. The x-ray maps for carbon, sulfur and oxygen in the passive film covering the surface along the crack revealed accumulation of sulfur in several locations near the crack. It appears that an iron-rich layer covers the crack tip.

The solution pH at 85°C plays a very important role in the passive film formation in the region of the propagating crack as well as on the planar (free) surface. This may be associated with different stability of sulfur species in the solutions with pH=7 and pH=9, which will be further studied.

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