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Effect of Sour Environment Temperature on Fatigue Crack Propagation in Ultrahigh-Strength 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 environmentally induced cracking (EAC) that includes corrosion fatigue, stress corrosion cracking and hydrogen/sulfide induced cracking.[2]. Temperature can also have a significant effect on failure mechanisms of alloys susceptible to EAC due to different solubility of H_2S and CO_2 in aqueous solutions at constant pressure. Solubility of these gases decreases with increasing temperature of the aqueous environment. There is no literature data on crack propagation mechanisms for ultrahigh-strength low alloy carbon steel drill pipe subjected to cyclic stresses in service environments at ambient and elevated temperatures. To fill the technological gaps on crack growth, the National Energy Technology Laboratory in collaboration with DNV has investigated the effect of the service environment temperature on fatigue crack growth rate (FCGR) in one of the candidate steels, UD-165.

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 as a function of frequency. The partial pressure of H_2S (p_{H2S}) was 0.83 kPa and the pH of the solution was 7. The fatigue experiments used a stress intensity ratio of 0.5 with stress intensity factor (ΔK) of 109.9 MPa$\sqrt{}$cm. Testing was performed at 20 and 200°C, respectively, in an autoclave with surface investigations of the region of crack growth augmented by scanning electron microscopy.

Figure 1 shows a topographic SEM micrograph for a crack that propagated from the starter notch in the normal test solution with pH=7 at 200°C. Accumulation of corrosion products is visible along the primary and secondary cracks. The EDX chemical analysis of the accumulated corrosion products over the crack tip found iron, nickel, and oxygen.

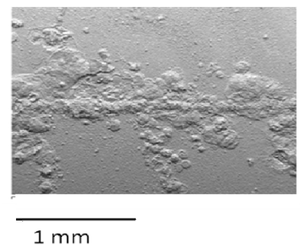

Fig. 1. Topographic SEM micrograph of UD-165 after a fatigue crack growth test in $NaCl/NaHCO_3/Na_2CO_3/p_{H2S}$ = 0.83 kPa at 200°C, pH=7.

The surface of the sample after fatigue crack growth testing in the sour environment with pH=7 at 20°C, Fig. 2, looks slightly different from the fatigued surface in the solution with pH=7 at 200°C.

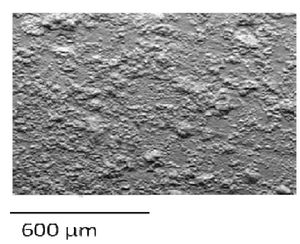

Fig. 2. Topographic SEM micrograph of UD-165 after a fatigue crack growth test in $NaCl/NaHCO_3/Na_2CO_3/p_{H2S}$ = 0.83 kPa at 20°C, pH=7.

The corrosion products cover the surface fairly uniformly. No spallation of the corrosion products was observed in this instance along the crack or near the notch. X-ray maps for carbon, sulfur and oxygen in the passive film that covered the surface was rich in iron, sulfur, oxygen, and carbon.

From comparison of these two conditions, it appears that the environment and temperature affects not only the crack propagation characteristics but also the general corrosion response of bare surfaces.

References:

1. S.A. Holditch and R.R. Chianelli, MRS Bulletin, 33 (2008), p.317.
2. M. Ziomek-Moroz, J. Mater. Eng. Perform., DOI: 10.1007/s11665-011-9956-6.