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Models for Environmentally Assisted Crack Growth in Ultra-high Strength Steel in Sour Environments

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Environmentally assisted cracking (EAC) of high strength steels is recognized as a serious cause for the catastrophic failure of components operating in sour environments. Over the years corrosion fatigue (CF), one of EAC phenomena, has been recognized as the main failure mode in approximately 75% of all catastrophic failures of drill strings during the drilling of shallow wells.[1] Taking into account that oil and natural gas will continue to be the main fuels in this century, even as a transition to more sustainable energy source mix takes place, research needs to be performed on cracking in drilling pipe under fatigue conditions in sour environments, especially crack propagation models. Literature data[2] indicate that understanding the degradation processes occurring at the crack tip during CF of structural alloys in aqueous environments is the best approach towards establishing CF models. The possible crack growth rate controlling steps in the hydrogen-enhanced corrosion fatigue process can be a surface reaction generating hydrogen, or diffusion of hydrogen through the fracture zone, and/ or stress corrosion cracking controlled crack growth.

For example, experimental evidence of hydrogen diffusion controlling process for CF in H_2S-containing environments could be the linear dependence between fatigue crack growth rate (FCGR) and frequency on a logarithmic scale with a slope of -0.5. The National Energy Technology Laboratory in collaboration with DNV is currently working on developing models for CF in advanced drilling steels as functions of simulated sour well environment parameters (temperature, pressure, pH).[3] Grade UD-165 is one of the ultra- high yield strength carbon steels developed for drilling ultra deep oil and natural gas wells.

The FCGR behavior of UD-165 was investigated by monitoring crack growth rate in deaerated 5%NaCl solution buffered with $NaHCO_3/CO_2$ and in contact with H_2S as a function of frequency. The partial pressure of H_2S (p_{H2S}) was 8.3 kPa and pH of the solution was 7. The fatigue experiments used a stress intensity ratio of 0.13 with stress intensity range (ΔK) of 315.4 MPa√cm. Testing was performed at 20°C in an autoclave with surface investigations augmented by scanning electron microscopy (SEM).

Figure 1 shows fatigue crack growth rate (FCGR) as a function of frequency on a logarithmic scale. The relationship between FCGR and frequency is linear with a gradient of -0.5. This indicates that FCGR is controlled by the hydrogen diffusion.

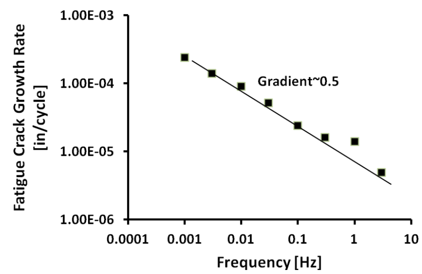

Fig. 1. FCGRas function of frequency for UD-165 in $NaCl/NaHCO_3/CO_2/p_{H2S}$ = 8.3 kPa at 20°C, pH=7.

The crack morphology near the tip in UD-165 after the fatigue testing in the sour environment (pH=7) at 20°C is shown in Fig. 2.

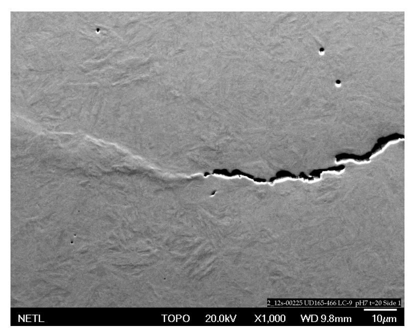

Fig. 2. Topographic SEM of UD-165 after a fatigue test in $NaCl/NaHCO_3/CO_2/p_{H2S}$ =8.3 kPa at 20°C, pH=7.

The primary crack is shown. At the crack tip, the plastic deformation zone is visible. This may be caused by hydrogen accumulation that diffused into the material. Further investigations are in progress.

References:

1. M. Ziomek-Moroz, J. of Materi. Eng. and Perform. DOI: 10.1007/s11665-011-9956-6.
2. R.P Wei and R.P. Gangloff, Fracture Mechanics: Perspective and Directions, ASTM, 1989, p.223-264.
3. T. Ramgopal, F. Gui, J. Hawk, and M. Ziomek-Moroz, Corrosion 2011, Paper no. 11108.