Studies on Hydrogen Enhanced Fatigue and Effect of Overload in a Cu-Strengthened High Strength Low Alloy Steel

Arijit Roy (Roll No: 05MT9505)
Metallurgical and Materials Engineering Department
Indian Institute of Technology Kharagpur

ABSTRACT

Assessment of material integrity and life estimation demands systematic investigation of the fatigue behavior properties under constant amplitude as well as variable amplitude of loading. The present study has been devoted to study the fatigue behavior of a high strength low alloy steel in various environments with a special emphasize on influence of hydrogen on fatigue. To understand the role of sustained passive films on crack growth, a part of this work investigated crack growth in a spontaneously passivating media. The crack growth and closure were examined for fatigue loading of an HSLA steel in non-corroding media. Stress ratio (*R*) as well as stress intensity factor range (ΔK) significantly influence crack growth retardation in NaOH. Presence of a passive film at high *R* and self repair of the film and formation of an additional oxide layer at low *R* could explain this retardation.

The influence of hydrogen on fatigue crack growth rates (FCGRs) was studied with in-situ hydrogen charging as a function of operational parameters like frequency of loading (*f*), ΔK and *R*. A constant ΔK loading as well as increasing/decreasing ΔK loading protocol was used to delineate the stress intensity effect from other factors. A normalized FCGR was used to isolate the hydrogen contributions to FCGR, thereby allowing us to distinguish the parametric effects on hydrogen embrittlement (HE) during cyclic loading. It was observed that the hydrogen effect increased with decreasing ΔK, with decreasing stress ratio and with increase in crack length. These effects could be explained by considering a compressive stress zone ahead of the crack tip that developed on unloading. This stress zone was responsible for pumping out hydrogen from the near crack tip regions. The reduced hydrogen as well as the absence of tensile stresses needed for hydrogen embrittlement, led to a decrease in the FCGRs when the compressive stress region was large. The changes in fracture surface with crack progression were consistent with the relative influence of hydrogen during the course of a test. The difference in the FCGR for increasing and decreasing ΔK tests could also be explained by the changes in ΔK and crack length during the course of a test, which modulated the hydrogen availability at the crack tip. The frequency effect, bearing an inverse relationship of frequency with FCGR, could be due to a combination of factors like non-availability of critical hydrogen content in the process zone and the loading strain rate variation with frequency. A dependence of normalized FCGR with crack length was observed which has implications on life prediction formulations. The crack length effect was due to a combination of operational stress, $\Delta\sigma$, and strain rate, in addition to hydrogen enhancement by bulk charging. Thus the normalized FCGR as well as the overall FCGR depends on multiple factors each modulated by the imposed operational and derivative parameters. The fractographic observations corroborated the hydrogen effects.

In view of the very limited literature on hydrogen interaction with overload leading to modified crack growth recovery, a systematic investigation was conducted to bring out the issues like the changes in crack growth mechanisms and the effect of hydrogen concentration, on the post-overload crack growth. The effect of compressive stress ahead of the crack tip on modulating crack growth has been discussed. The hydrogen concentration, through its influence on hydrogen availability ahead of the crack tip, is shown to influence crack growth rate recovery after overloads. The fractographic observations are shown to validate the explanations.