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SUBCRITICAL CRACK GROWTH IN HIGH-PRESSURE HYDROGEN AND HYDROGEN WITH OXYGEN IMPURITY

Robert W. Wheeler[1]*, Chris San Marchi[1], and Joseph Ronevich[1]
[1]*Hydrogen and Materials Science Department, Sandia National Laboratories*
Livermore, CA, USA
**Presenting Author email: rwheel@sandia.gov*

Abstract
In this study, the effects of oxygen content on hydrogen environment-assisted cracking are studied for several pipeline and commercial steels. Characterizing the effects of low oxygen impurities in hydrogen gas on subcritical crack growth in high pressure hydrogen environments can help inform fracture mechanics-based design and evaluate if oxygen can be utilized to mitigate hydrogen effects over long timescales.

1. Introduction

Hydrogen is known to induce subcritical crack growth in pipeline steels whereas the addition of relatively low amounts of oxygen (e.g. 100 or 1000PPM) have been shown to have mitigating effects on fatigue crack growth rates in laboratory tests [1, 2]. For this study, constant displacement fracture tests were carried out in high pressure (103 MPa) pure hydrogen and mixed gas (100PPM and 1000PPM oxygen + hydrogen) environments. The effects of oxygen content on time to crack propagation (incubation time), crack growth rates, and crack arrest thresholds are characterized in this work.

Constant displacement bolt-loaded wedge-opened loaded (WOL) samples were precracked in air to a crack length (a) of a/W = 0.55, where W is the specimen width. Three steels were characterized in the study: X100 pipeline steel, ASME SA-372 Grade L and ASME SA-372 Grade J with a yield strengths (YS) of 760 MPa, 730 MPa, and 700 MPa, respectively. Preload values (applied stress intensity factor, K_{app}) were selected based on previously reported data for equivalent materials in pure hydrogen environments [1]. The experimental configuration, shown in Figure 1a, included an instrumented reaction pin such that the load could be monitored throughout the duration of the experiments (approx. 3 months). Figure 1b is a representative fracture surface, which shows the extent to which the crack propagated during exposure to the high-pressure mixed gas environment.

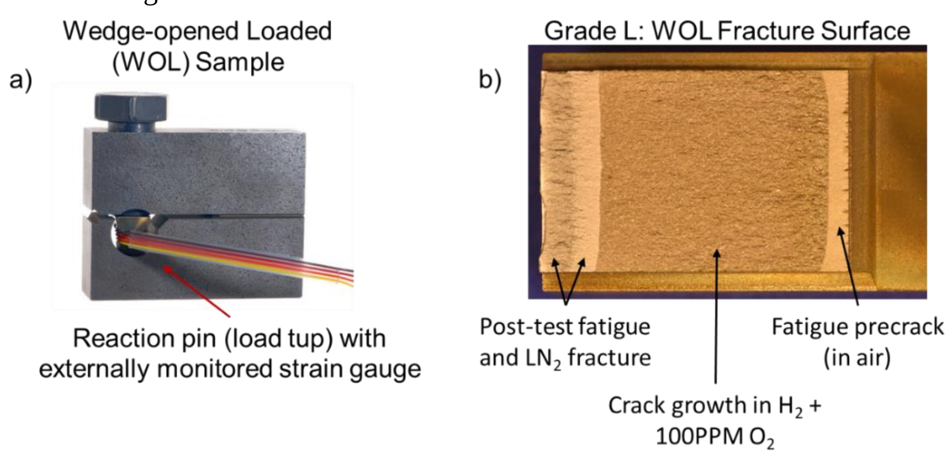

Figure 1: a) Example of a loaded WOL sample with an instrumented reaction pin b) Representative fracture surface showing the fatigue precrack, crack growth in environment, and post-test fracture.

2. Results

The addition of 100 and 1000PPM oxygen to the high-pressure hydrogen environment was found to increase the crack incubation time for all materials and loading conditions. However, cracking did occur in these alloys and the oxygen did not affect the crack growth rates or arrest threshold, K_{th} (*i.e.* K value when the crack propagation finishes). The incubation time for crack propagation is shown in Figure 2 for both the Grade L and Grade J materials with different preloads for pure hydrogen environments (black), 100PPM oxygen mixed gas (blue), and 1000PPM oxygen mixed gas (orange). The high-strength line pipe steel

(X100) showed similar response. While the largest relative increase in incubation times came from the addition of 100PPM oxygen, the 1000PPM oxygen tests had consistently longer delays prior to crack propagation.

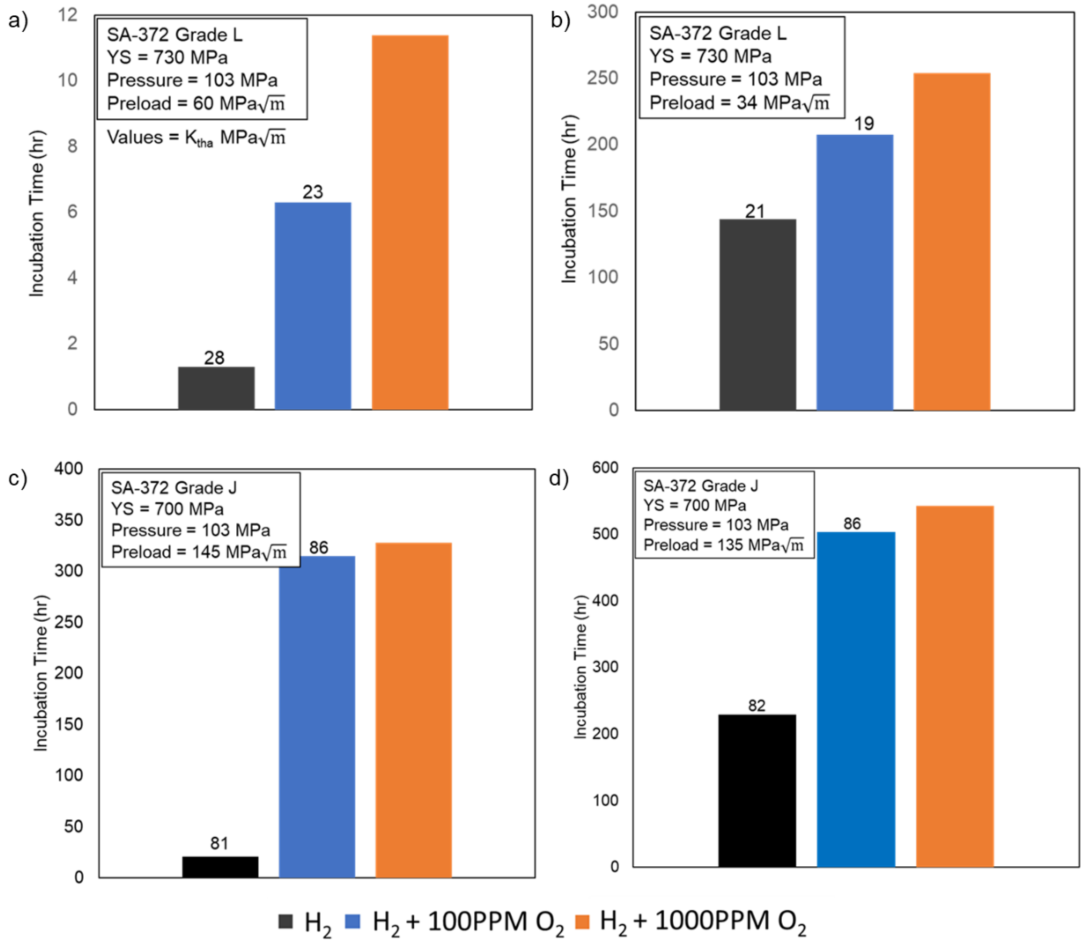

Figure 2: Incubation times for WOL samples in pure hydrogen and hydrogen with 100 and 1000 PPM oxygen for Grade L and Grade J samples with varying preloads.

3. Conclusions

While the addition of oxygen was found to delay the crack propagation, it did not prevent subcritical crack growth as all materials did crack. The presence of the oxygen did not have an effect on either the crack growth rates or arrest threshold (*i.e.* value of K when the crack propagation finishes). This suggests that oxygen should not be relied upon for long-term mitigation of hydrogen embrittlement.

4. References

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[2] B. Somerday, P. Sofronis, K. Nibur, C. S. Marchi and R. Kirchheim, "Elucidating the variables affecting accelerated fatigue crack growth of steels in hydrogen gas with low oxygen concentrations," Acta Materialia, vol. 61, no. 16, pp. 6153-6170, 2013.

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