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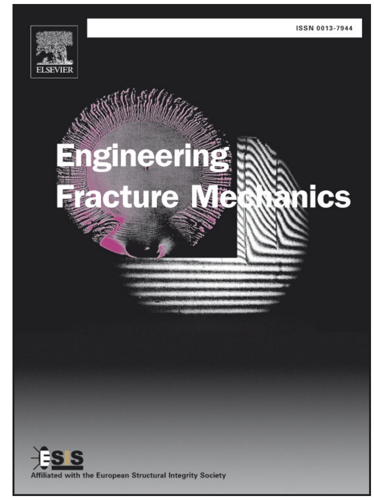

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Fatigue crack growth rates of X100 steel welds in high pressure hydrogen gas considering residual stress effects

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Abstract:

Fatigue crack growth rate (FCGR) data were measured in high pressure hydrogen gas versus stress intensity factor range (ΔK) in specimens removed from a X100 welded steel pipe. Three distinct regions of the pipe weld were examined: base metal, weld fusion zone, and heat affected zone. Tests were performed at a load ratio (R) of 0.5, frequency of 1 Hz, and at a hydrogen gas pressure of 21 MPa. Tests were also performed in air at 10 Hz as a reference. Fatigue crack growth rates were observed to be over an order of magnitude higher for tests performed in hydrogen compared to the rates from tests in air. Residual stress measurements were collected on identical specimens cut from the base metal, weld, and heat affected zone to account for their influence on measured FCGR data. The slitting method provided residual stress and residual stress intensity factor (K_{res}), the effect of which was removed from the FCGR data using K_{norm} in order to provide a more direct comparison of crack growth resistance of the base metal, weld and heat affected zone. Prior to accounting for residual stress, FCGR in hydrogen gas appeared to be highest in the weld fusion zone. After accounting for residual stress effects, the weld fusion zone FCGR data converged to the base metal FCGR data, which underscores the importance of accounting for residual stress effects when assessing fatigue performance.

Keywords: Hydrogen embrittlement, residual stress, high strength pipeline steels, fatigue crack growth rate, high pressure hydrogen

1. Introduction:

Steel transmission pipelines have provided a safe and reliable system for transporting hydrogen gas for many decades. This has been demonstrated through the thousands of kilometers of hydrogen pipe operated in the United States and Europe [1]. However, the network of hydrogen pipes is typically operated at relatively modest and constant pressures, e.g. below 14 MPa. As the demand for hydrogen increases, the operating pressure of the pipelines is anticipated to expand beyond the current operating envelope and fluctuations of pressure may be incurred on the pipes. While the current infrastructure of hydrogen pipelines is a testament to their reliability, the prospect of changed operating conditions needs to be considered judiciously. Pipeline operation at higher pressures with variations in demand has the potential to generate fatigue loading through pressure cycling. Pressure cycling can promote a failure mode that is otherwise non-existent when the pipe is operated under static conditions, i.e. hydrogen accelerated fatigue crack growth. In this embrittlement phenomenon, fatigue cracks can grow more than 40 times faster in a hydrogen environment compared to their growth in air [2-5].

Higher strength hydrogen steel pipelines are an attractive pathway to reduce costs as outlined in a recent paper [6]. The natural gas industry employs thin-walled, high-strength pipes for cost savings. However, for hydrogen pipelines and applicable pipeline code, ASME B31.12, thickness limits are currently placed on higher strength pipes. The added thickness premium nullifies the cost savings that would be gained if similar codes such as the natural gas code ASME B31.8 were permitted. Part of the