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Hydrogen Induced Fatigue Crack Growth in Pipeline Steel API 5L X65: A Combined Experimental and Modelling Approach

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Abstract : Climate change is driving a transition in the energy sector, with low-carbon energy sources such as hydrogen (H2) emerging as an alternative to fossil fuels. However, the successful implementation of a hydrogen economy requires an expansion of hydrogen production, transportation and storage capacity. The costs associated with this transition are high but can be partly mitigated by adapting the current oil and natural gas networks, such as pipeline, an important component of the hydrogen infrastructure, to transport pure or blended hydrogen. Steel pipelines are designed to withstand fatigue, one of the most common causes of pipeline failure. However, it is well established that some materials, such as steel, can fail prematurely in service when exposed to hydrogen-rich environments. Therefore, it is imperative to evaluate how defects (e.g. inclusions, dents, and pre-existing cracks) will interact with hydrogen under cyclic loading and, ultimately, to what extent hydrogen induced failure will limit the service conditions of steel pipelines. This presentation will explore how the exposure of API 5L X65 to a hydrogen-rich environment and cyclic loads will influence its susceptibility to hydrogen induced failure. That evaluation will be performed by a combination of several techniques such as hydrogen permeation testing (ISO 17081:2014), fatigue crack growth (FCG) testing (ISO 12108:2018 and AFGROW modelling), combined with microstructural and fractographic analysis. The development of a FCG test setup coupled with an electrochemical cell will be discussed, along with the advantages and challenges of measuring crack growth rates in electrolytic hydrogen environments. A detailed assessment of several electrolytic charging conditions will also be presented, using hydrogen permeation testing as a method to correlate the different charging settings to equivalent hydrogen concentrations and effective diffusivity coefficients, not only on the base material but also on the heat affected zone and weld of the pipelines. The experimental work is being complemented with AFGROW, a useful FCG modelling software that has helped inform testing parameters and which will also be developed to ultimately help industry experts perform structural integrity analysis and remnant life characterisation of pipeline steels under representative conditions. The results from this research will allow to conclude if there is an acceleration of the crack growth rate of API 5L X65 under the influence of a hydrogen-rich environment, an important aspect that needs to be rectified instandards and codes of practice on pipeline integrity evaluation and maintenance.

Keywords : AFGROW, electrolytic hydrogen charging, fatigue crack growth, hydrogen, pipeline, steel
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