WP3 TASK 3.2

Material aspects in hydrogen and methane infrastructure

ABSTRACT

This task seeks to identify the critical material aspects of hydrogen-based infrastructure, including pipelines, storage facilities (such as underground storage), and network components. It also examines the essential material considerations necessary for converting methane-based infrastructure, namely natural gas systems, to hydrogen. Key aspects studied include the impact of hydrogen on materials. Critical material properties analysed include strength, ductility, and toughness, which are susceptible to potential hydrogen-induced embrittlement. Fatigue performance was deemed crucial in the conversion of natural gas pipelines. The fatigue crack growth rate is up to 100 times faster in a hydrogen environment compared to a methane environment. Linear Elastic Fracture Mechanics (LEFM) has proven effective as a tool for assessing the feasibility of conversion and for evaluating inspection intervals in relation to fatigue-related issues.

MOTIVATION

Use of existing natural gas (methane) infrastructure is considered to be one enabler of the hydrogen economy as is provides a potential opportunity for economical transportation of hydrogen especially in the early phase of the development with lower transport capacity needs. However, natural gas pipelines feature significantly thinner walls than dedicated hydrogen pipelines due to different characteristics of these gases and their influence on metallic materials properties. Therefore, the natural gas pipelines should only be utilized after careful case by case implementation of best practices and modifications suggested in various studies. Also, real-time monitoring tools for pipelines should be developed and implemented to ensure the safe use and efficient inspection of pipelines with pipeline inspection gauges (PIGs).

RESULTS

Linear elastic fracture mechanics (LEFM) provides a connection between existing structures and numerical methods and was therefore used to model fatigue crack growth. An example of this kind of modelling technique is illustrated in Figure 1 with typical equations needed for fatigue life assessment. This kind of monitoring during the service is needed to verify the safety of non-standardized structures.

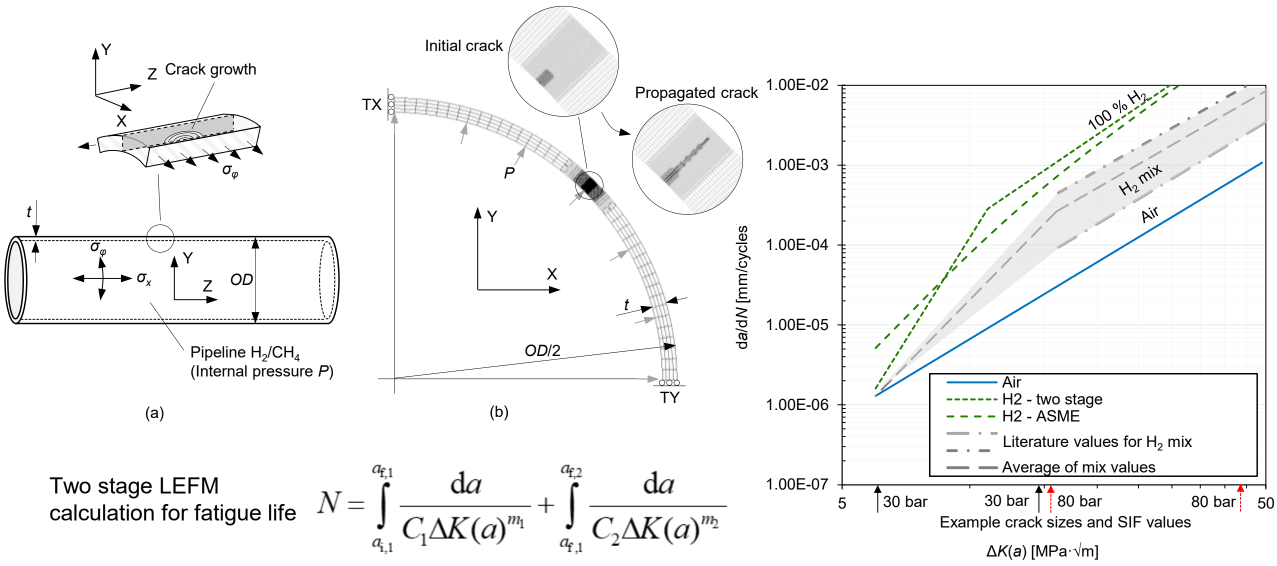

Figure 1. Stress intensity analysis of fatigue crack in the pipeline.

The result of the analysis is demonstrated in Figure 2. Reasonable fatigue life, measured as maximum operational pressure cycles, are shown as a grey shading from 5000 to 20 000 pressure cycles. Initial crack depth of 2 mm (inspectable crack size) and 1 mm (manufacturing condition, not inspectable) are used as a basis for analysis and the reasonable converted pressure for hydrogen transport can be seen when green or blue line overlaps shaded area. The results show that natural gas pipeline with 80 bar rated pressure could operate as re-purposed hydrogen pipeline with 50 bar pressure.

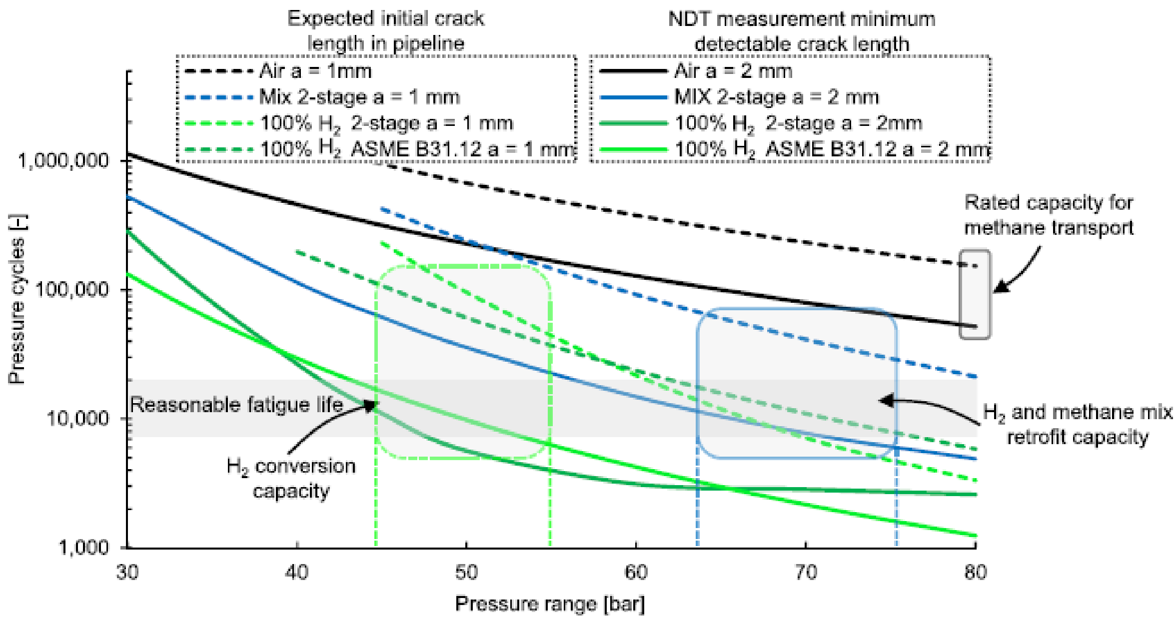

Figure 2. Fatigue life described as maximum operational cycles in respect to rated pressure and operational windows for hydrogen and methane transport in the same pipeline.

The fatigue life of a pipeline can be divided into six phases and each phase has its main determining factor (Figure 3). The initial crack size (in phase: initial crack size in the pipeline) is determined by manufacturing quality. The smallest inspectable crack size is around 2 mm in the depth direction. The final crack size (in phase: critical crack size) is determined by yield strength and fracture toughness.

From this inspectable crack depth, the introduced calculation procedure was used to estimate safe crack growth length before analytical method indicates that pipeline inspection was needed. Non-destructive testing (NDT) inspecting then verifies the situation and lifetime estimation can be updated.

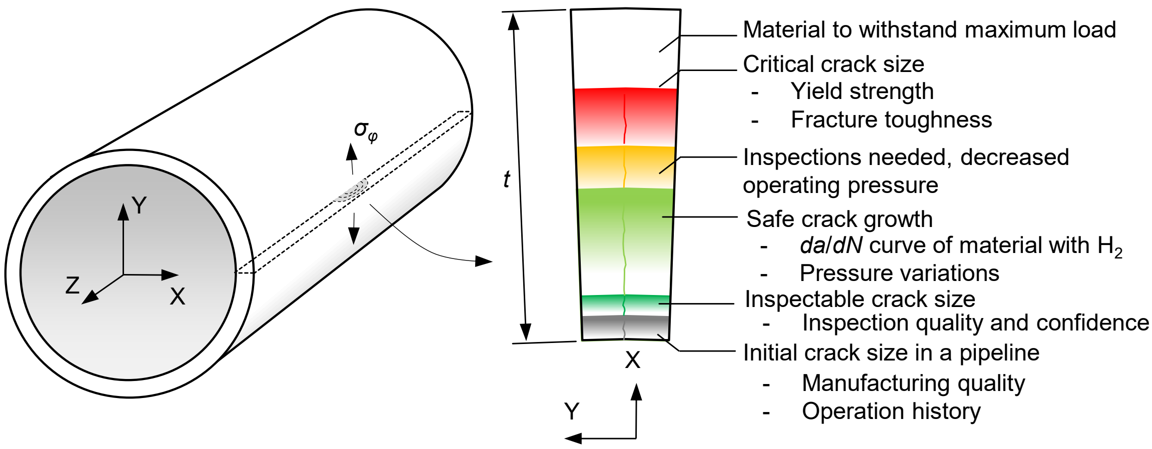

Figure 3. Characteristic fatigue crack growth rate phases and the main influencing factors of them in a hydrogen pipeline.

APPLICATIONS/IMPACT

This work identified possibility to mix methane and hydrogen in existing pipelines and conversion for hydrogen transport with numerical fatigue crack growth analysis. The used LEFM enables evaluation of conversion and estimates inspection interval and potential remaining lifetime for hydrogen transport. The study indicated that existing natural gas pipelines could be utilized for hydrogen transport when maximum operation pressure is decreased, and fatigue life monitoring is applied together with inspection plan.

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