RP3.1-01: Knowledge Gap Analysis for Fracture Control of Future Fuels Pipelines and Recommendations for Future Work

Background

Hydrogen has been identified as a future fuel that could reduce carbon emissions, while continuing to provide the benefits of gas in a future decarbonised economy. However, it is known that hydrogen behaves differently to natural gas and will affect the design and operation of steel pipelines.

Most significantly, hydrogen will dissociate and permeate into steel and change its material properties, a process known as hydrogen embrittlement. This could potentially cause a pipeline to fail prematurely. The likelihood of fracture initiation would increase, and, if fracture initiation should occur, the ability of the steel to arrest the fracture could also be compromised. Consequently, hydrogen cannot safely be introduced into the gas network until the effects of hydrogen are understood sufficient that they can be predicted.

Research Goal

This project was the first project that the Future Fuels CRC executed to study the effect of hydrogen on steel pipelines. The purpose was for the research team to become conversant with the significant issues that hydrogen can create, by studying existing research and existing published standards.

The research had the following goals:

- Review of standards and recommended practices pertinent to the fracture control of pipelines transporting hydrogen
- Review of studies on the impact of hydrogen on standard material properties (tensile properties, fracture toughness and fatigue)
- Review of test methods for understanding the impact of hydrogen on standard material properties
- Review of studies on the dispersion and flammability of hydrogen and natural gas mixtures
- Review fracture control methodologies and testing methods for future fuels pipelines,
- Review past and present projects along with existing infrastructure relevant to future fuels technology
- Provide recommendations for future work with a roadmap to guide the delivery of the Commonwealth Schedule 2 – Activities related to fracture control of future fuels

Research Activities

These goals were achieved by means of a detailed literature review, and through visits to several hydrogen testing facilities worldwide.

B31.12 is the only existing standard for explicitly delivering hydrogen through transmission pipelines. This standard is reviewed at a high level in the report.

Visits were made to:

- Material Testing Institute at MPA University in Stuttgart, Germany,
- Bundesanstalt für Materialforschung und –prüfung (BAM) (Federal Institute for Materials Research and Testing) in Berlin, Germany, and
- Sandia National Laboratory in Livermore, California, USA.

The visits informed the researchers of the factors that need to be considered to do hydrogen testing. These will be used by the University of Wollongong in setting up a laboratory in Australia for gaseous hydrogen charging and testing of steels.

Outcomes

The key outcomes identified from these reviews identified the following key impacts of hydrogen:

Tensile properties

- Hydrogen has consistently been shown to reduce the total elongation and final reduction area of steels.
- Note that existing fracture initiation models do not take these parameters into account when predicting plastic collapse failure.
- The hydrogen concentration in the steel is a key factor in the observed changes of material properties. Data indicates a critical concentration beyond which more pronounced changes in tensile properties occur.

Fatigue

- Fatigue crack growth rate (FCGR) as a function of stress intensity increases by up to two orders of magnitude in a hydrogen environment than in a nitrogen or air environment
- The effect of mean stress has not widely been reported on and should be investigated
- Fatigue life of a pipeline carrying a hydrogen/methane mixture is indicated to be about one-tenth of that of a pure nitrogen mixture

Fracture initiation toughness

- The fracture mechanism of failure differs in the presence of hydrogen, with results indicating a mix-mode mechanism
- Little work has been conducted to assess how the Charpy and DWTT tests are influenced by hydrogen, resulting in difficulty correlating behaviour with existing pipeline failure models
- To determine the critical defect length for a pipe carrying hydrogen, full-scale fracture initiation tests need to be conducted

Fracture arrest toughness

- Burst Tests with pure hydrogen have been conducted and indicate shorter crack propagation and a more rapid decompression behaviour in comparison to methane tests. However, these tests were not designed to assess or measure the effect of hydrogen embrittlement on fracture propagation behaviour

Hydrogen release

- Experimental studies carried out for dispersion and explosion tests in enclosed spaces or open fields feature small release rates, and so may not be representative for a risk assessment of release from a transmission hydrogen/natural gas pipeline.
- Nevertheless, test rig, and measurement techniques development will be useful for future experimental studies.
- Very few comprehensive dispersion or ignition modelling studies intended to investigate the risk of hydrogen/natural gas transmission pipelines.

The final report serves as a foundation to direct future research by the Future Fuels CRC into fracture control methodologies for future fuel transport pipelines. Using this research, a research roadmap was prepared for a stream of work investigating hydrogen embrittlement through a combination of theory, laboratory-scale experiments, full-scale experiments, and international collaboration.

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