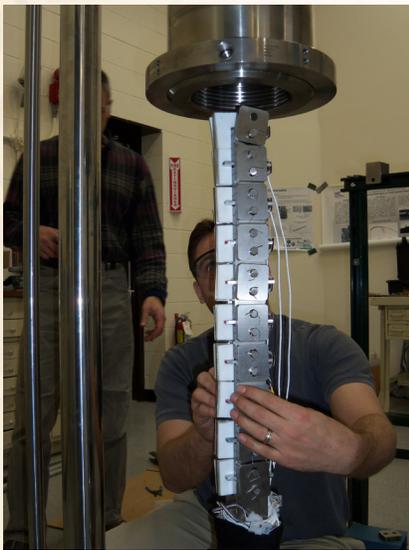
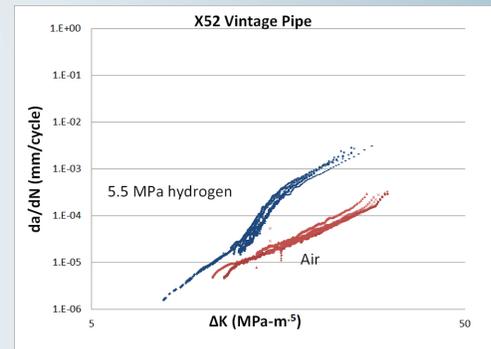


Hydrogen Pipeline Material Testing Facility

Objective

We provide critical data, measurement methods and models that enable safe and economical transport, delivery and storage of hydrogen fuel, an abundant, clean-burning alternative to conventional fossil fuels. Currently, we are generating fatigue data for pipeline materials including steel alloys currently being used (API X52), those proposed for use (newer versions of X52 as well as X65 and X70), and older pipelines made of X52 to X70 materials that might be repurposed. Using this data, we can model the performance of pipeline materials and make predictions about the safe operating limits of pipelines carrying pressurized gaseous hydrogen, thereby helping to inform and revise relevant codes and standards.



Impact and Customers

While pipelines are the safest, most economical way to transport fuels, the parameters used for codes and standards for the transport of hydrogen are based on tensile test data that is over 30 years old. In order to enable the design of safe pipelines and the use of hydrogen as an alternative fuel, a working understanding of the relationship between fatigue performance of pipeline steels and hydrogen gas pressure and loading parameters is needed.

Since pipelines operate at low loading frequencies, fatigue data takes a very long time to produce. NIST has developed a measurement system that reduces this time by a factor of 10.

Critical data from this project directly informs codes from ASME and CSA America.

Customers impacted by this work include ASME, CSA America, Evraz, Air Liquide, Praxair, El Paso, PG&E and others.

Based on 2011-2012 cost numbers from industry, use of X70 steel rather than X52 steel would result in a savings of over \$1 million per mile of pipeline.

Approach

NIST has a unique capability for measuring mechanical properties of structural materials in pressurized gases. Our primary focus is fatigue measurements in high-pressure hydrogen gas, but our capability is applicable to all high-pressure gas environments. We use two load frames, each outfitted with a high-pressure chamber for mechanical measurements. One chamber can test a single specimen in a gas atmosphere at up to 140 MPa, and the other can test up to 10 specimens simultaneously in up to 38 MPa gas. The measurements are remotely and automatically operated for safety, reliability and repeatability.

We test modern pipeline steels such as X52, which have low carbon for weldability and predominantly acicular ferrite microstructures. Because higher-strength alloys such as X70 would permit future pipeline designs to be even more economical, we are testing those as well. An efficient way to transport hydrogen could be achieved by re-purposing existing pipelines, so we are also measuring the fatigue properties of older alloys. Older alloys have different microstructures and different chemistries, and therefore may behave differently in hydrogen. While our focus has been on base materials, we will soon begin a systematic matrix of tests on seam and girth welds, including the weld itself and the heat-affected zone, from both old and new pipelines.

We have developed a model that uses the fatigue data and pipeline design inputs to predict the lifetime of a hydrogen pipeline. The model can predict fatigue crack growth rate as a function of operating pressure and load frequency, and can account for different microstructures. Estimates of lifetimes can be output as a function of existing flaw size.

Industry members of the ASME B31.12 Committee on Hydrogen Piping and Pipelines have given us guidance on which materials to test and continue to guide us on the priorities for the modeling effort. The data from this project are being used by the committee to modify the code; prior to this work there was no information on fatigue crack growth of pipeline steels in hydrogen gas.

Accomplishments

Our group has developed a test method that simultaneously measures 10 specimens at once, maintaining specific environmental and loading conditions until all 10 specimens have completed testing. Pipelines run at very low loading frequency, which generally increases their lifetime, expressed as the number of cycles until failure. However, with hydrogen, low loading frequency is an issue because the time per cycle is long enough for hydrogen to completely diffuse to a crack tip where damage per loading cycle is maximized. Therefore, testing of fatigue in these conditions requires low loading frequencies and long times. Before we invented our test methodology, it took too long to determine a set of critical data large enough to be of use to the industry. The unique NIST design allows the test to continue until all 10 specimens are measured before opening the test chamber, minimizing testing time.

Two load frames, each with a high-pressure test chamber, can be run simultaneously and at different hydrogen (or other gas) pressures. The plumbing for gas supply was designed and built to operate in a fail-safe manner, so that—upon loss of power, air

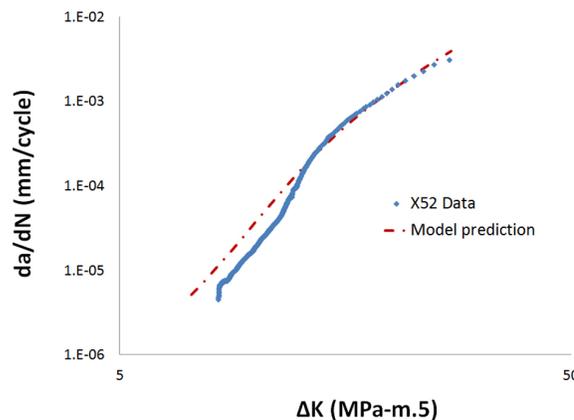


Figure 1. Data for X52 and model prediction for a representative measurement of X52 at 34MPa hydrogen gas and 1 Hz loading frequency at $R=0.5$

pressure or ventilation—numerous interlocks prevent further gas supply to the laboratory. Additionally, hydrogen sensors monitor the laboratory for leaks. A program was developed to automate the gas supply and pressure maintenance of the two high-pressure test chambers. This program also monitors all power and safety systems so that the gas supply system can be shut off in an orderly manner upon sensing one of the interlocks. An additional program was developed to allow remote monitoring of the system. This program also sends automatic text messages to members of the team if any critical error is encountered by the system, such as a hydrogen alarm, loss of compressed air or loss of laboratory ventilation.

We have measured fatigue crack growth rate on over 70 specimens, including six steel alloys. Each set of 10 specimens that we simultaneously test includes both sample seam and girth welds. This data is regularly presented to the ASME B31.12 committee. This data has allowed us to quantify the effects of gas pressure and loading frequency on the rate of fatigue crack growth. We have observed differences in fatigue crack growth rate between newer, acicular ferrite and older ferrite/pearlite microstructures.

We have developed a phenomenological model of fatigue crack growth rate as a function of hydrogen gas pressure and load frequency and constitutive relations have been added that provide a predictive capacity. Figure 1 is a preliminary application to a new X52 alloy. We have done a

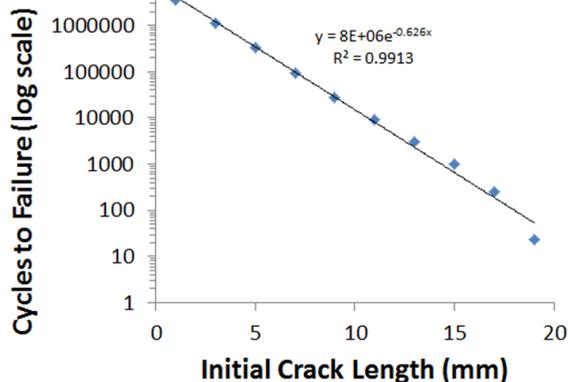


Figure 2. Lifetime prediction generated from the model as a function of initial crack length, based on representative fatigue crack growth data

parametric sensitivity analysis that will aid real-life pipeline design. Parameters that pipeline operators would use, such as pipe wall thickness, operating pressure, pressure ratio and loading frequency are used as inputs and lifetime in the form of number of cycles to failure is given as the output. Figure 2 shows a representative sensitivity analysis of initial crack size, generally defined as the limit of a detectable crack. Different types and geometries of cracks result in different initial flaw size, and the model can account for crack size, as well as crack geometry.

NIST has worked with industry partners from the ASME B31.12 Committee on Hydrogen Piping and Pipelines and CSA America task group on compressed hydrogen materials compatibility to develop a matrix of tests that includes different strengths of alloys and varying ages and microstructures. The first few years of work has focused on measurement of base metals, while future work will focus on seam and girth welds, once again measuring material from alloys of varying strength, age and microstructure.

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Publications

NE Nanninga, AJ Slifka, YS Levy, and C White, A review of fatigue crack growth for pipeline steels exposed to hydrogen, *J. Res. NIST*, **115** (6) 437-452 (2010).

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