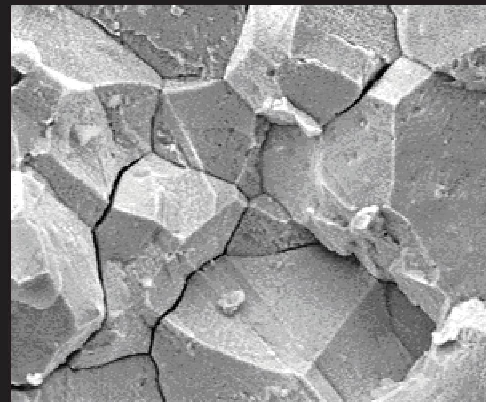
Hydrogen Pipeline Safety

Objective

Our goal is to establish the codes and standards necessary to ensure safe distribution of hydrogen fuels. The future "hydrogen economy" will depend on efficient transport of fuel across the U.S., preferably using our existing network of oil and gas pipelines where hydrogen degradation is likely to occur. By establishing unique test facilities and standard test procedures, we will provide pipeline operators with critical data on the durability of pipeline materials in high-pressure gaseous hydrogen environments.



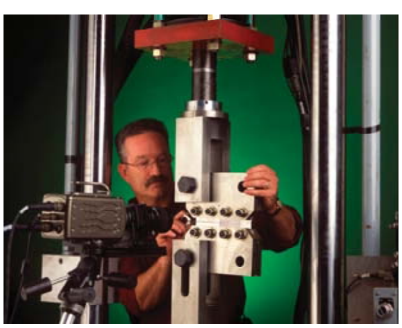
METALS

Impact and Customers

- Gasoline consumption in the U.S. exceeds 44 million gallons per day, much of which must be imported. Dependence on foreign fuel threatens our international position and introduces security risks. Switching to hydrogen as a primary energy source will increase domestic control and substantially reduce greenhouse gas emissions.
- 700 miles of hydrogen pipelines are currently in operation in the U.S. (compared to > 1M miles of natural gas pipelines). These are concentrated near refineries and chemical plants, operate at low pressures, and require nearly constant safety inspection. Materials optimization and sensor development will accelerate the transition to large-scale hydrogen distribution.
- NIST is working with DOT, DOE, ASME, British Petroleum (BP), Pacific Gas and Electric (PG&E), TransCanada, the Northeast Gas Association, Pacific Energy, Pipeline Research Council International (PRCI), the Public Service Enterprise Group (PSEG), BJ Services (Canada), Fox-Tek (Canada), and Rosen Inspection on sensor development and steel testing.

Approach

We are currently constructing a new laboratory to evaluate tests, materials, mechanical properties, and standards for hydrogen pipelines. Construction is just beginning on the 750-square-foot laboratory on the site of a former hydrogen test facility at the NIST campus in Boulder, Colorado. The laboratory, including a control room in a separate existing building, is expected to be operational by mid-2008. NIST researchers will use the hydrogen laboratory to develop long-term service tests and apply them to study pipeline materials and mechanical effects.



Experiments will involve immersing materials in pressurized hydrogen gas contained in steel alloy test chambers. The largest of these, about the size of a small automobile gas tank, will be the nation's biggest hydrogen test chamber. Studies will be conducted using hydraulic machines to test mechanical fatigue, tensile strength, residual strength and fracture toughness. Initial research will involve collecting data for existing pipeline materials as a baseline and conducting "round robin" exercises to ensure consistency of tests among various hydrogen laboratories. In the future, the focus will expand to new materials such as composites.

Accomplishments

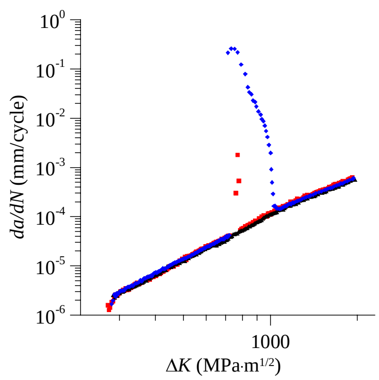
To prioritize our experiments once facility construction is complete, MSEL recently held a workshop on Test Procedures for Hydrogen Pipelines. This meeting brought together pipeline owners and operators, standards organizations, academic researchers, and scientists and program managers from other national laboratories and government agencies. The workshop report (NIST-IR 6649) includes a ranked list of materials and test methods which will serve as a guide for the initial test activities in the new hydrogen facility.

In particular, the workshop discussed further development of the crack-tip-opening-angle (CTOA) test method as a potential standard test procedure for hydrogen fatigue. CTOA is becoming one of the more widely accepted properties for characterizing plastic fracture, especially in running ductile cracks in pipes. Our existing research on CTOA for high-strength pipeline steels (*e.g.*, API-X100) will be used as a baseline for gaseous hydrogen testing of these materials.

Prior to being able to perform high-pressure gas testing, we conducted preliminary tests to evaluate the effects of hydrogen on the fatigue life of such steels for DOT. Electrochemical hydrogen charging was conducted at the Colorado School of Mines (Golden, CO). Specimens were prepared with and without surface tinning to determine its effects on hydrogen dissolution. Our results show a two-orders-of-magnitude increase in fatigue rate when specimens were hydrogen-charged.

Compact tension specimens for H_2 testing

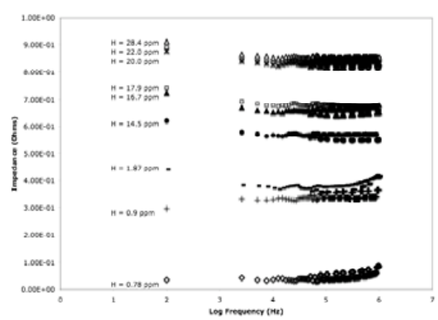
In the graph below, the deviation from the straight line shows the effect on the fatigue crack growth rate over a 25-minute test period.



Effect of hydrogen on fatigue rate

In addition to determining the effect of hydrogen charging on steel fatigue, we are also developing non-destructive sensors to measure the extent of hydrogen permeation in the steel in real time. By establishing a quantitative measure of hydrogen content during testing, we will be able to better correlate mechanical response with hydrogen uptake.

Extremely sensitive electronic and magnetic property measuring systems are now available which correlate material functionality and microstructure, phase, or interstitial content, providing a non-destructive measurement approach. For example, thermoelectric power measurements, in conjunction with Beeghly ester-halogen digestion (nitride determination), have been successfully developed to quantitatively map soluble nitrogen content in nitrogen-strengthened austenitic stainless steel welds. We have recently shown that this same method can be used to monitor the reversibility of hydrogen storage in LaNi5 and to determine diffusable hydrogen content in coated steel linepipe specimens. The figure below shows the effect of hydrogen content on impedance for a series of X80 steel specimens. The graph clearly shows that the impedance increases with increasing hydrogen content. This work is being performed in conjunction with a DOT-funded research project aimed at improved pipeline inspection methods.



Impedance as a function of hydrogen

Learn More

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Publications

Darcis PhP, McCowan CN, Windhoff H, McColskey JD, Siewert TA, *Crack Tip Opening Angle Optical Measurement Methods in Five Pipeline Steels*, Engineering Fracture Mechanics 75: 2453 (2008)

Lasseigne AN, Anton JM, Siewert TA, Olson DL, Mishra B, and Jackson JE, *Advanced Non-Destructive Measurement Scheme to Actively Monitor Hydrogen Content in Steel Pipelines*, Proc. QNDE 2007, AIP (2007)

Siewert TA, McColskey JD, and Ricker RE, *Report of NIST Workshop on Materials Test Procedures for Hydrogen Pipelines*, NISTIR 6649 (2007)

Lasseigne AN, Olson DL, Kleebe HJ, and Boellinghaus T, *Microstructural Assessment of Nitrogen-Strengthened Austenitic Stainless-Steel Welds Using Thermoelectric Power*, Metal&MaterTrans A 36A: 3031 (2005)