# Pipeline Safety

## Objective

Our goal is to provide standard test methods and critical data to the pipeline industry to improve safety and reliability. Of particular interest is the testing of high-strength pipeline steels, which could enable higher volume gas transport and reduce energy costs. However, characterizing the ductile fracture properties of these materials is difficult, limiting their use due to safety concerns. We are developing new methods to test these materials to enable pipeline designers to better predict fracture dynamics and make better informed material selections.

METALS

## Impact and Customers

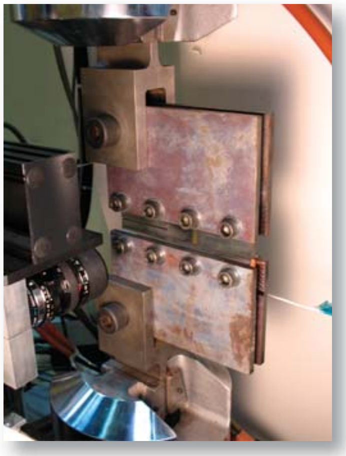
- The U.S. operates 2.4M miles of natural gas and hazardous liquid pipelines, crossing all 50 states. From 1989-1998, 2241 pipeline accidents occurred, resulting in 226 deaths, 1030 injuries, $700M in property damage, and release of 1.5M barrels of crude oil and gasoline. The 2002 Pipeline Safety Act was a direct response to disastrous pipeline accidents worldwide.

- In 2006, BP Alaska was forced to shutdown its Prudhoe Bay facility due to a corroded, leaking pipe, ultimately replacing nearly 16 of its 22 miles of pipe at a cost of $170M. Replacement with high-strength steel could have reduced costs by 30% if data had been available to support safe use.

- NIST is working with DOT, DOE, British Petroleum (BP), Pacific Gas and Electric (PG&E), TransCanada, the Pipeline Research Council International (PRCI), and the International Society of Offshore and Polar Engineers (ISOPE) on testing requirements for strain-based design. Here, high-strength steels may offer exceptional benefits (seismic loading, arctic loading, and pipeline reeling; strains exceed 4 %).

## Approach

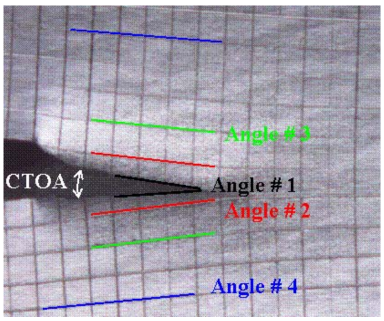
We are adapting the Crack Tip Opening Angle (CTOA) method to testing pipeline steels. CTOA is becoming one of the more widely accepted properties for characterizing fully plastic fracture, especially for running ductile cracks in pipes. It can be measured directly from the crack opening profile and can be related to the geometry of the fracturing pipe. In cases where there is a large degree of stable-tearing crack extension during fracture, CTOA can measure fracture resistance. Our research focuses on improving the optical imaging technique for determining the opening angle.

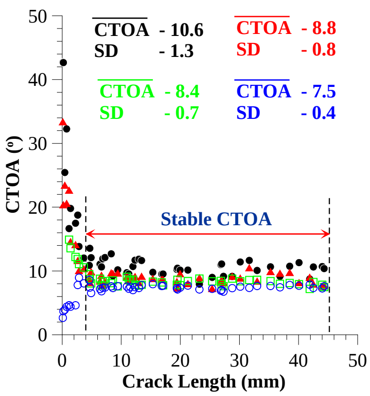


In addition to CTOA test development, we also measure the fatigue properties of different pipeline steels at full thickness to provide data on predicted pipeline performance. Specimens are machined directly from the pipeline longitudinal axis. To date, the fatigue behavior of six pipeline steels have been investigated.

# Accomplishments

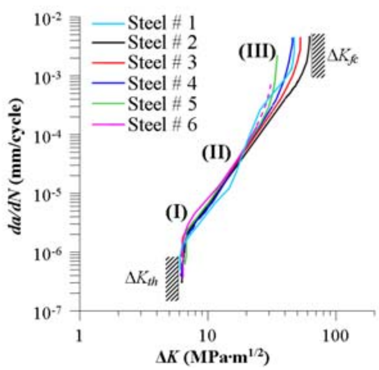
The method used to determine CTOA can introduce uncertainty into the fracture resistance. We directly measured CTOA at the crack tip edges in accordance with the optical method referenced in the ISO and ASTM (E2472) draft standards. However, within the specific ranges, we varied the reference points at different distances from the crack, resulting in significant variability (increased standard deviation or SD), particularly for method 1, where data from the crack profile were referenced to points back from the crack tip.

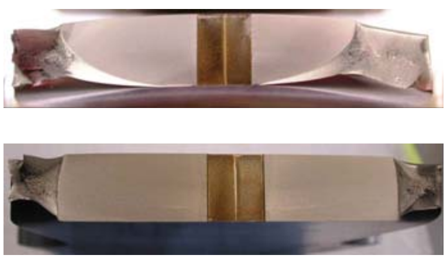



*Effect of image analysis on CTOA*

CTOA tests have been performed on four different steels, while fatigue tests have been performed on six different materials covering a range of strengths. Results showed minor differences in the threshold values of the steels, in stage I and for most of stage II. Some changes are observed for the fatigue critical stress intensity factors for the steels in stage III. Residual stress effects were observed for Steel #1, which was coated with a corrosion inhibitor. The residual stress led to uneven crack growth through the pipe, resulting in a higher apparent fatigue threshold.



*Fatigue data for 6 different steels; upper image: uneven crack growth for Steel #1; lower image: symmetrical crack growth typically observed*

In addition to experimental studies, NIST has worked closely with the pipeline industry to ensure we are addressing their highest priority measurement needs today and in the future. For example, NIST has an ongoing collaboration with DOT's Office of Pipeline Safety to advance technology for the construction, repair, and inspection of pipelines. One goal of this collaboration is to identify critical research needs of the pipeline community, such as the development of higher-strength steels and methods for improved fatigue characterization of these materials.

In January 2006, DOT and NIST sponsored the "Advanced Welding and Joining Technical Workshop: Pipelines." The workshop included ~70 participants representing pipeline owners, technology developers, trade and standards organizations, and government agencies. The workshop participants refined and raned research needs. Of particular interest was the role that NIST can play in advancing strain-based design principles. Pipelines have historically used stress-based designs. Strain-based designs offer advantages for high-strain applications (up to 4 %). However, significant testing is required to define weld strain capacity, qualify the base metal, determine critical flaw sizes, and qualify weld procedures. NIST is working with DOT to provide test support and experimental data.

## Learn More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## Publications


Darcis PhP, Treinen, JM, McColskey, JD, *Fatigue Crack Growth Rates in Pipeline Steels Using Curved M(T) Specimens*, J.Test.Eval., submitted

Darcis PhP, McCowan CN, Windhoff H, McColskey JD, Siewert TA, *Crack tip opening angle optical measurement methods in five pipeline steels*, EngrFractureMech 75: 2453 (2008)

Darcis PhP, McColskey JD, McCowan CN, and Siewert TA, *Exploring Methods for Measuring Pipe Weld Toughness*, Welding Journal, June 2007

Bussiba A, Darcis PhP, McColskey JD, McCowan CN, Kohn G, Siewert TA, Smith R, Merritt J, *Fatigue crack growth rates in pipeline steels and fatigue life prediction*, Proc. IPC 2006, Calgary, Canada (2006)