

Preliminary Analysis of Tensile Strain Capacity of Full-Scale Pipe Tests with Internal Pressure

Yong-Yi Wang
Center for Reliable Energy Systems
Dublin, OH, USA

Mark Stephens
C-FER Technologies
Edmonton, Alberta, Canada

David Horsley
BP Canada Energy Company
Calgary, Alberta, Canada

ABSTRACT

Wide plate tests have been recognized as the “benchmark” for measuring the tensile strain capacity of pipeline girth welds. Numerical analysis in recent years, however, showed that the tensile strain capacity of a pipe could be reduced by the application of internal pressure. A series of full-scale experimental tests of 12.75-inch OD X65 ERW pipes were conducted with and without internal pressure to examine the effects of internal pressure on tensile strain capacity. The test setup was carefully designed to provide high quality data for the validation of prior numerical predictions and for the development of future predictive models. The background information leading to the current work is first reviewed in this paper. The design of the full-scale tests, including the instrumentation plan and test setup is described. The initial test results are shown in conjunction with numerical simulation of the results. Overall the test results conclusively demonstrated that the tensile strain capacity of pipelines having circumferential planar defects could be reduced by 50% or more when internal pressures equivalent to Classes 1 and 2 designs are applied. The reduction in tensile strain capacity is consistent with predictions from numerical models.

KEYWORDS: strain-based design, tensile strain capacity, fracture mechanics, ductile fracture, pipeline

INTRODUCTION

Curved wide plate (CWP) tests are often viewed as being able to produce “benchmark” data of the tensile stress and strain capacities of pipeline girth welds. For instance, wide plate test data were the basis of the Tier 2 EPRG Guidelines on girth weld defect acceptance criteria [Hopkins, et al., 1991] with plastic collapse as the limit state [Denys, 1992, 1995]. In the context of strain-based design, wide plate tests have been used to determine tensile strain capacity [Denys et al., 2000, 2004a, 2004b] and even for welding procedure qualifications [Hukle, et al., 2005]. The newly published tensile strain limit procedures in CSA Z662 Annex C were extensively validated against CWP test data [Wang, et al., 2006a].

There is strong evidence from numerical analysis in the recent years that the tensile strain capacity of a pipeline could be reduced by the

application of internal pressure [Liu and Wang, 2007]. It was found that the crack driving force of planar girth weld flaws was significantly increased under applied longitudinal strain if an internal pressure is applied prior to the longitudinal loading. It was not known, however, whether the resistance of material to the ductile initiation and growth of a flaw would change by the application of internal pressure. Recently published full-scale test data appear to support the numerical prediction of reduced strain capacity by internal pressure [Ostby and Hellesvik, 2007]. However in some of the tests of Ostby and Hellesvik [2007] the final failures were not by tensile rupture at the flaw location. This makes the quantitative comparison less than ideal.

A research program was initiated in 2006 to examine the effects of internal pressure on tensile strain capacity. The objective of the program was to provide high-quality full-scale test data to validate prior predictions from numerical models and to provide experimental data basis for the development future predictive models.

The full-scale tests involved 12.75-inch (324-mm) OD \times 0.5-inch (12.7 mm) wall thickness ERW pipes. Surface-breaking planar flaws, simulating planar girth weld flaws in field welds, were artificially introduced to the pipes. The pipes were first pressurized and then pulled in pipe longitudinal direction until leakage is detected in the flaws. This paper covers the initial work of this research program. The focus is on the preparatory work in specimen design and instrumentation plan for the full-scale tests. The initial test results are reported here; while the full coverage of the test results and post-test data analysis is deferred to future publications.

REVIEW OF TENSILE STRAIN CAPACITY

Crack Driving Force Approach

One of the methods in determining the tensile strain capacity is the concept of the crack driving force (CDF) approach. The relation between the CDF (as measured by crack tip opening displacement, or CTOD driving force) and the remote longitudinal strain is developed for a range of defect size, material, and geometry conditions [Wang, et al., 2004a, 2004b, 2004c; Horsley and Wang, 2004]. This approach is similar to the generic CTOD design curve and the crack driving force curve approach of SINTAP [SINTAP,