Compressive Strain Limits of Large Diameter X80 UOE Linepipe

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ABSTRACT

For arctic pipeline systems, designers are required to deal with a number of unique environmental loading conditions not normally present in other regions of the world. For buried arctic onshore pipelines, the key structural design issue is the potential for high bending strains resulting from permafrost: frost heave and/or thaw settlement. Because of the lack of traditional design solutions to these unique deformation-controlled loading conditions, reliability-based limit state design methods are becoming increasingly preferred for arctic applications. They allow the integration of analytical and experimental assessments into the overall design philosophy, which has been shown to improve design concept confidence and reduce overall uncertainty.

For a strain-based design approach, high pipeline bending strains due to deformation-controlled ground movements are addressed as a function of the defined allowable tensile and compressive strain limits. Excessive compressive strains may give rise to serviceability issues such as restricted pipeline pig passage or coating damage. In some cases, excessive compressive strains may compromise pipeline integrity due to other loads and could lead to ultimate limit state conditions associated with burst, fatigue or corrosion under damaged coating.

To further develop the understanding of pipeline compressive strain capacity, this paper summarizes a test program performed at the C-FER Technologies (1999) Inc. (C-FER) testing facility in Edmonton, Canada, which quantified the critical compressive strain of 36-inch diameter, 19.8-mm wall thickness, grade X80 UOE linepipe. Test variables included heat treatment effects (simulated coating plant heating) and the presence of a girth weld. Test involved performing thermal treatment studies, material coupon tests and three full-scale bend tests on X80 UOE linepipe specimens subject to high internal pressure.

As expected, the analysis of the results has shown that the presence of an offset in the girth weld reduced compressive strain capacity. It was also demonstrated that, although heat treatment increased the Y/T ratio, it did not have a significant impact on the slope of the stress-strain curve in the region where buckling occurred, thus resulting in no loss of local buckling capacity.

Equations to predict critical buckling strain, which agree well with the full-scale test results, were formulated based on published work. These equations consider the influence of varying stress-strain curve shape.

KEY WORDS: Linepipe, heat treatment, Y/T ratio, testing, buckling, strain limit, strain-based design.

NOMENCLATURE

\( AR \) as-received (non-thermally-treated) test sample
\( \delta \) girth weld offset
\( \Delta \theta \) angle change between ends of a gauge length
\( E \) Young’s modulus
\( \varepsilon \) strain
\( \varepsilon_c \) compressive strain
\( \varepsilon_{cr} \) critical buckling strain
\( \varepsilon_n \) neutral axis strain (strain measured at the elastic neutral axis of the specimen)
\( HT \) heat-treated pipe sample
\( HT-GW \) thermally-aged pipe sample with a girth weld
\( ID \) inside diameter
\( K \) curvature
\( K\text{-type} \) chromel-alumel thermocouple
\( L \) length
\( m \) metre
\( mm \) millimetre
\( MN \) meganewton
\( MPa \) megapascal
\( n \) hardening coefficient (Ramberg et al. 1943)
\( OD \) outside diameter
\( P \) pressure
\( P_y \) yield pressure = \( \frac{2 \sigma_{ty}}{OD} \)
\( OD \) outside diameter
\( SMYS \) specified minimum yield strength