Evaluation Precept for Buckling Resistance of High-Strength UOE Line Pipes Used in Strain Based Design (SBD) Applications

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Strain capacity is required for line pipes used in strain based design (SBD) applications. This paper deals with the buckling resistance of UOE line pipes under the bending moment, and discusses the methodology for evaluating the strain capacity. The critical condition, in which the compressive strain limit is minimized, was found by modeling the geometric imperfection of a pipe with the strength distribution under the bending moment. Comparing the minimum strain limit with the prediction by the single stress–strain (S–S) curve, the sampling position was optimized. The higher correlation to the strain limit was obtained by sensitivity analysis using the measured S–S curves. Consequently, reliable methods have been suggested for SBD.

NOMENCLATURE

D_A = nominal diameter, mm
D_B = minimum diameter, mm
D_C = maximum diameter, mm
L = pipe length, mm
n = integer of wavelength
SMIP = specified minimum internal pressure
t = wall thickness, mm
Uel = uniform elongation
w = radial displacement of pipe radius, mm
x = axial position, mm
Y/T = yield-to-tensile strength ratio
α = geometric imperfection
β = geometric imperfection range, mm
ε_{cr} = compressive strain limit
θ = angle of inclination at pipe end, rad
λ = buckling wavelength, mm
ν = Poisson's ratio
$\sigma_{1\%}/\sigma_{5\%}$ = ratio of 1%- to 5%-flow stress
ϕ = bending orientation, deg

INTRODUCTION

In pipelines crossing discontinuous permafrost, ground movement due to frost heave and subsidence generates high stress beyond yield stress (YS). The plastic design method such as SBD is applied to such hostile environments (Glover, 2004). The main performance of the pipes required for SBD is the buckling resistance and the girth weld strength under the bending moment with the internal pressure. Such performance properties have been evaluated by the full-size bending tests and the curved wide plate tests in experiments. A numerical attempt has been made to show the effect of the mechanical properties on the strain capacity by modeling the pipe with the geometric imperfection and the girth weld

(Ishikawa, 2003; Torselletti, 2005; Vitali, 2005). Recently, it is noted, the thermal aging during the anti-corrosion coating changes the mechanical properties (Shinohara, 2005; Timms, 2005).

UOE pipes are commonly used for the line pipe in SBD applications. Since UOE pipes are manufactured by cold pressing, they have not only the strength anisotropy but also the strength distribution. While a few attempts have been made to clarify the strength anisotropy (Tsuru, 2005; Vitali, 2005; Liu, 2006), few studies have been undertaken to investigate the change in the strength distribution in the thermal aging and its effect on the buckling capacity.

The objectives of this study are to measure the strength distribution, to demonstrate the effect of the strength distribution on the strain capacity, to determine the sampling position for conservative estimation of the buckling limit, and to introduce the mechanical property index showing the high correlation to the strain capacity.

To measure the strength distribution representing the entire region of the pipe, the strain analysis in 762-OD × 15.6-t, X80, was performed for the UOE pipe forming process using FEA, and thus the sampling positions to obtain S–S curves were selected. The strength distribution was measured after the thermal aging, 240°C × 5 min. Applying such S–S curves to the FEA model of the UOE pipe with the geometric imperfection, the combined effect of the strength distribution and the seam weld was evaluated for determining the decisive sampling position. To evaluate the seam weld integrity, ring expansion tests were conducted.

As a result of the tests, the strain capacity becomes minimum under 45° of the angle oriented between the seam weld position and the bending direction. The results suggest that 80% to 90° from the seam weld are the best sampling positions for conservative estimation of the strain capacity. The ring expansion test verified that the seam weld maintained the joint integrity within the expected strain limit. As the highest correlation of the mechanical property index to the compressive strain limit, ε_{cr}, $\sigma_{1\%}/\sigma_{5\%}$ was suggested as the new index.

TEST PROCEDURE

The experimental approaches were performed to measure the strength distribution by the coupon sample tests and to evaluate the joint strength of the seam weld by the ring expansion test.