ABSTRACT

This paper deals with the buckling behavior of UOE pipes under bending moment, and proposes reliable evaluation methods for the compressive strain limit ($\varepsilon_{\text{limit}}$). Full-scale bending tests were performed to evaluate the effect of change in the mechanical properties during the anti-corrosion coating and the geometric imperfection induced by the intentionally mismatched girth weld. During the numerical simulation, the pipe was modeled using the measured pipe profile and the material constitutive law newly developed to analyze the orthogonal anisotropy. The test results verified that $\varepsilon_{\text{limit}}$ was not degraded by aging, although it declined for pipes with girth welds. The numerical model gave a good prediction for $\varepsilon_{\text{limit}}$, hence revealing that the mechanical property in circumference affects the buckling resistance of UOE pipes. To analyze the effects of material characteristics, simplified models were proposed and the results obtained from the validated models suggest that the conventional method using the isotropic work hardening law may overestimate $\varepsilon_{\text{limit}}$ under high internal pressure.

KEYWORDS: line pipe; UOE pipe; buckling; strain limit; thermal aging; work hardening; anisotropy; yield function

NOMENCLATURE

$w$: radial displacement of pipe radius, mm  
$\alpha$: geometric imperfection  
$\varepsilon_{\text{comp}}$: compressive strain  
$\varepsilon_{\text{limit}}$: compressive strain limit  
$\varepsilon_{\text{neutral}}$: strain at neutral position  
$\varepsilon_{\text{i}}$: strain just after internal pressure  
$\theta$: angle of inclination on both sides of the wrinkle, rad  
$\lambda$: buckling wavelength, mm  
$v$: Poisson’s ratio

INTRODUCTION

Design technique, or a so-called strain-based design (SBD), is applied for line pipes buried in discontinuous permafrost subject to ground movement such as frost heave and subsidence, while tensile and compressive strain limits are considered into SBD, represented by the joint integrity of the girth weld and the buckling resistance of the pipe body (Glover, 2004, Barbas, 2007). This paper describes the buckling resistance of UOE linepipes under a bending moment with internal pressure, which is the typical loading condition in discontinuous permafrost. Generally, bending deformation is allowable up to the peak moment, since local buckling leads to excessively high strain inducing pipe burst. The early local buckling increases the maintenance cost of pipelines.

Many studies note that the major dominating factors for pipe buckling include the material characteristics and the pipe geometries (Suzuki, 2003, Tsuru, 2007). Pipe manufacturers have developed line pipes with high strength and deformability, which are mainly designed by chemical compositions and TMCP (Thermo Mechanical Control Process) condition during the plate manufacturing process (Shinohara, 2005, Ishikawa, 2008). However, the plastic working in the pipe forming and the strain aging by heat during the anti-corrosion coating change the mechanical properties of the plate. Both forming and aging result in significant orthogonal anisotropy, whereby the stress vs. strain (SS) curve differs between longitudinal (L-) and circumferential (C-) directions (Liu, 2006, Wang, 2007, Treinen, 2008). Many attempts have been made to show the effect of the L-SS curves on buckling resistance, although the undeveloped constituent model of the material prevents us from solving the effect of the orthogonal work-hardening anisotropy.

Regarding the pipe profile, the geometric imperfection caused by the