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Effect of Misalignment on the Tensile Strain Capacity of Welded Pipelines

S. A. Kibey, K. Minnaar, J. A. Issa, and P.C. Gioielli
ExxonMobil Upstream Research Company
Houston, Texas, USA.

ABSTRACT

Reliable characterization of tensile strain capacity of welded pipelines is a key issue in development of strain-based design methodologies for weld and material qualification. However, limited guidance is available on factors governing strain capacity of welded pipelines. In this paper, the effect of misalignment on tensile strain capacity of X60 and X80 welded pipelines with different diameters and wall thicknesses is examined using finite element analysis (FEA). The FEA results indicate weld misalignment has a significant influence on tensile strain capacity for both the plastic and fracture limit states. Furthermore, tensile strain capacity is strongly influenced by wall thickness and capacity has a relatively weak dependence on pipe diameter. The study illustrates a need to incorporate the observed effect of misalignment in experimental programs designed to characterize strain capacity for development of next generation fracture assessment procedures. Finally, a non-dimensional parameter is developed for use in simplified strain capacity assessment procedures.

KEY WORDS: Pipeline strain capacity, Fracture mechanics, Strain-based design, Pipeline girth welds, Fracture toughness, Misalignment

INTRODUCTION

In response to meet the world energy demand, the oil and gas industry has moved towards development of resources in remote regions with seismically active zones and arctic climates. Pipelines operating in seismic regions may be subjected to finite plastic strains exceeding 0.5% due to soil movement, while pipelines in discontinuous permafrost regions may undergo significant plastic deformations (~1 to 2 %) due to thaw settlement or upheaval buckling. Traditional stress based design is typically inadequate for qualification of welds in such harsh environments. Hence, a strain-based design guideline for qualification of welded pipelines subjected to finite deformations is essential.

Limited guidance is available on the design, qualification and assessment of welded pipelines that may be subjected to large strains in service. Majority of design codes are stress based and are not proven to be applicable to load conditions under large deformation. Typically, these codes are based on classical fracture mechanics approaches using fracture parameters such as K_I and J integral, which are well established for small scale yielding conditions. Two parameter fracture mechanics approach has been utilized to account for the size effects in real structures [O'Dowd and Shih, 1991]. However, two parameter fracture mechanics approaches have not been validated in the large scale yielding regime or when extensive crack growth occurs. Furthermore, J-R curves and CTOD-Δa curves have been shown to be geometry dependent under large-scale plastic deformation conditions [Gibson and Druce, 1987; Cottrell and Atkins, 1996] and this geometric dependence was recently verified to hold for pipeline structures [Gioielli, Minnaar, Macia and Kan, 2007]. It is, therefore, not clear if current two parameter approaches can be used reliably to design girth welded pipelines subjected to finite plastic strains.

Previous studies have examined the effect of misalignment on tensile strain capacity of pipelines [Mohr, 2004; Ostby, 2005; Ostby, 2007; Wang and Liu, 2007] and have shown that misalignment can lead to increased crack driving force. To account for misalignment effects, some of these studies have proposed the use of "effective" crack depths. However, more work is needed to quantify the influence of the observed increase in driving force on strain capacity of welded pipelines.

The present work focuses on determining the effect of geometric factors on the strain capacity of girth welded, pressurized pipelines. Parameters investigated include wall thickness (WT), outer diameter (OD), weld misalignment, circumferential flaw length (C), and flaw height (a). A sensitivity study using 3-D finite element models is described and the results are discussed to evaluate the relative importance of the parameters. Finally, a non-dimensional parameter is proposed to relate the influence of OD, WT, a and C on strain capacity.

FAILURE MECHANISMS AND LIMIT STATES

Multiple physical processes act simultaneously to determine the capacity of a welded pipeline. ExxonMobil embarked on a detailed experimental program to characterize failure processes active under conditions of large deformation and pressure loading and published the first data of welded full-scale pipe tests with weld overmatch levels ranging from 0% to 20 %. Details of the experimental program are published in the First Strain Based Design Symposium held at the 2007 ISOPE conference in Lisbon Portugal [Gioielli, Minnaar, Macia and Kan, 2007; Fairchild, Cheng, Ford, Minnaar,Biery, Kumar and Nissley, 2007; Minnaar, Gioielli, Macia, Bardi and Biery, 2007]. The experimental data and accompanying numerical analysis showed two physical processes control the tensile limit state: ductile fracture and plastic collapse. Two modes exist for plastic collapse. The first, localization (necking), occurs at the flaw location in the remaining WT