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Tensile Strain Limits of X80 High-strain Pipelines

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ABSTRACT

This paper presents the preliminary studies performed with finite element analysis (FEA) and experiments focused on the tensile strain limit of X80 pipelines under large axial and bending loads. Specifically, it investigates the effects of design factors and the strain capacity of the girth weld and the base material on the ductile crack limit, with particular emphasis on equivalent plastic strain at the notch tip. In addition, the strain capacity of a 30" pipeline is also considered by comparing tensile strain and equivalent plastic strain at the notch tip corresponding to a critical compressive strain which occurs at the local buckling under the pure bending.

KEY WORDS: gas pipeline, X80 grade, high-strain pipe, strain capacity, strain limit, pure bending, ductile crack initiation

INTRODUCTION

In recent years, a large number of natural gas pipeline development projects have been planned for permafrost regions and seismic regions (Glover, et al., 2003). The fact that pipelines laid in such regions are subjected to large plastic strain as a result of ground movement due to repeated thawing and freezing of frozen ground (Cayz, et al., 2003) and lateral flow (ground movement due to liquefaction), fault movement, etc. due to earthquakes. Likewise, in pipeline design methods, strain-based design is began to apply instead of stress-based design.

On the other hand, pipelines using high strength and thin-walled material exceeding X80 grade have been desired as a means of improving gas transportation efficiency and reducing construction costs. Consequently, high deformation capacity and high strength/high toughness properties are needed in the base material and welds of pipelines which are to be laid in such regions.

As the fracture mode in pipelines designed on a strain-based, local buckling and girth weld fracture from the defect under large deformation have been studied (Mohr, et al., 2004) (Mohr, 2006). In particular, to prevent fractures from welded joint, a lot of efforts have been made in recent years to realize the high toughness by optimization of the chemistry design of welding consumables and innovations in welding techniques. Accordingly, the most critical fracture mode in high strength pipelines is considered to be ductile fracture originating from defects in girth welds, and prediction of ductile crack initiation has been proposed as one of the sufficiently conservative assessment (Sadasue, et al., 2003).

At the microscopic level, ductile cracks occur as a result of the formation of voids from inclusions, followed by growth and consolidation. Because these processes are strongly influenced by stress triaxiality and equivalent plastic strain, it is known that ductile cracking can be assessed with good accuracy by the so-called 2-parameter method(Otsuka, et al., 1980) (Toyoda, et al., 2001)., which focuses on these conditions. However, it has not been enough conducted to the application of this method to objects under biaxial stress, such as actual pipelines, which are subjected simultaneously to hoop stress due to high design pressure and large axial strain due to large deformation.

From these backgrounds, this paper investigates the effects of design factors and the strain capacity of the girth weld and the base material on the ductile initiation, with particular emphasis on equivalent plastic strain at the notch tip. In addition, the limit state of a 30" pipeline is also considered by comparing tensile strain and equivalent plastic strain at the notch tip corresponding to a critical compressive strain which occurs at the local buckling under the pure bending.

EXPERIMENTAL PROCEDURE

Tested Materials

The welding conditions used in preparing welded joints are shown in Table 1, and a macroscopic photograph of a joint is also shown in the table. The base material is X80 grade steel plate for linepipe use (thickness: 24mm). The girth joint was prepared by GMAW welding. The welding conditions simulated the welding conditions for girth welds in actual pipeline construction. Typical tensile properties of the base material and weld metal and a tensile stress–strain (S-S) curve are shown in Table 2 and Fig.1, respectively. The weld metal overmatches the base material in both YS and TS. The S-S curve of the base material is a roundhouse type, and has Y/T ratio of 76% and uniform elongation of 11%.