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The Influence of Internal Pressure on Ductile Fracture Behavior from a Surface Defect on a Pipe

Takahiro Sakimoto, Satoshi Igi, Takahiro Kubo
Steel Research Laboratory, JFE Steel Corporation
Chiba, Chiba, Japan

Mitsuru Ohata and Fumiyoshi Minami
Division of Materials and Manufacturing Science, Graduate School of Engineering, Osaka University
Suita, Osaka, Japan

ABSTRACT

This paper presents the influence of internal pressure on ductile fracture behavior conducting three pressurized and un-pressurized pipe tension tests with machined surface notches. Especially, it is focused on investigation of the ductile crack initiation from the aspects on effective opening displacement at a notch tip. The influence of internal pressure was negligible on ductile crack initiation from a surface notch. On the other hand, the crack driving force became higher as internal pressure increased. Ductile tearing resistance curves (R-curves) obtained from pressurized pipe tests and Single Edge Notched Tension (SENT) tests are also investigated. A R-curve from SENT tests shows good agreement with that from pipe tests. Therefore, it is possible to use the R-curve of a SENT specimen as that of a pressurized pipe specimen. According to these results, the critical strain on ductile crack initiation and leakage of the pressurized pipe was predicted, and it is verified that predicted critical strain was well in agreement with an experimental result.

KEY WORDS: ductile crack initiation; tearing resistance; SENT test; internal pressure; crack propagation;

INTRODUCTION

In recent years, construction of natural gas pipelines is expanding to severe environmental area such as seismic or permafrost region (Glover, 2003). In these regions, it can be expected that pipelines will be subjected to large deformation due to large ground movement associated with liquefaction in seismic region or frost heave in permafrost. It is not possible to apply conventional stress-based design or integrity assessment methods in cases where a pipeline is subjected to large plastic strain that greatly exceeds the yield stress of the pipe material. A number of studies have been carried out on strain-based design and integrity assessment methods. Tensile strain limit of a pipeline is usually characterized using uni-axial tests such as the curved wide plate (CWP) test (Denys, 2004). Accordingly, the most critical fracture mode in pipelines is considered to ductile fracture originating from defects in girth welds, and prediction of ductile crack initiation of CWP test has been proposed using critical equivalent plastic strain at notch tip obtained from SENT tests (Sadasue, 2004). The tensile strain capacity of ductile crack initiation decreases as Y/T ratio of the base metal increases (Igi, 2007).

On the other hand, there is an increasing demand of high-pressure operation due to high efficiency of natural gas transportation. However, CWP tests could not take into account the effect of internal pressure. Therefore it is important to investigate the effect of internal pressure on ductile fracture behavior. Pressurized and un-pressurized pipe tensile tests have been conducted to investigate the influence of internal pressure on the tensile strain capacity of a pipeline (Gioielli, 2007, Minnaar, 2007). These tests indicated that internal pressure does not seem to affect R-curves. However it is not mentioned the influence of internal pressure on ductile crack initiation. Furthermore, with respect to the influence of internal pressure on the ductile crack initiation and growth, only a few data are available because of the difficulty of pressurized pipe tension test.

From these backgrounds, the influence of internal pressure on the ductile crack initiation and ductile tearing behaviors are investigated by conducting pressurized and un-pressurized tension tests using pipe specimens with machined surface notches. R-curves obtained from pipe and SENT tests are also investigated. According to these results, the critical strain on ductile crack initiation and leakage of the pressurized pipe was tried to predict using SENT and FEA results.

EXPERIMENTAL PROCEDURE

Tested Material

The test specimens were taken from JIS STPG 370 seamless pipes with 216.3mm of outside diameter (OD) and 10.3mm of wall thickness (WT). Typical tensile properties of the material and nominal stress-nominal strain (S-S) curve are shown in Table 1 and Fig. 1, respectively.

Table 1 Tensile properties in L-direction

YS [MPa]	TS [MPa]	uEL [%]
261	449	19.5