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Application of WES2808 to Brittle Fracture Assessment for Gas Pipelines

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ABSTRACT

This paper presents the results of a preliminary study to establish an assessment method for the tensile strain limit against brittle fracture of pressurized gas pipelines subjected to axial tensile deformation. The basis of the assessment method is the Japan Welding Engineering Society standard WES2808-2003, which provides a procedure for evaluating the fracture limit using the CTOD design curve taking into account the deterioration of the fracture toughness of materials due to large cyclic straining and dynamic straining. Modifications of the procedure to enable evaluation of the fracture properties of high strength gas pipelines under biaxial loading conditions are studied. The applicability of the CTOD design curve is investigated and problems with the CTOD design curve are clarified.

KEY WORDS: Pipeline; fracture assessment; high strain; tensile strain limit; axial loading; internal pressure; CTOD toughness

INTRODUCTION

In recent years, construction of pipelines has expanded to arctic, sub-arctic and seismic regions. Gas pipelines traversing discontinuous permafrost areas are subject to repeated frost heave and thaw settlement caused by variations in operating and surrounding temperatures. In this case, the pipelines may be subjected to large cyclic strain. Pipelines in seismic regions may also be subjected to large cyclic strain by landslides. In order to secure the integrity of pipelines subjected to large cyclic strain, a compressive strain limit for initiation of local buckling/wrinkling in the pipe wall and a tensile strain limit for initiation of fracture from girth weld flaws are important parameters (Zhou, Horsley and Rothwell, 2006). Therefore, numerous researchers have made significant efforts to predict these strain limits.

It has been recognized that the bending compressive strain capacity of linepipes is dependent on the D/t ratio (Glover, 2002; Suzuki and Toyoda, 2002), the strain-hardening properties of the pipe material (Suzuki and Toyoda, 2002; Suzuki et al., 2001), internal pressure (Suzuki et al., 2004) and geometric imperfection (Suzuki et al., 2006). It has also been reported (Suzuki et al., 2006) that the bending capacity of linepipes can be predicted accurately by finite element analysis (FEA) taking into account the actual values of these factors.

On the other hand, studies of the tensile strain limit have focused mainly on procedures that relate the girth weld strain limit to material properties and defect size (Wang et al., 2004). Equations for the relationship with these parameters have been proposed based on fracture mechanics and experimental data (Wang, Cheng and Horsley, 2004; Wang et al., 2006).

The Japan Welding Engineering Society published a standard WES2808-2003 (Method of assessing brittle fracture in steel weldments subjected to large cyclic and dynamic strain) whose main objects are architectural steel frame structures subjected to cyclic and dynamic large straining due to seismic loading. WES2808 employs a CTOD design curve relating tensile strain, fracture toughness (CTOD) and defect size, and gives limit values for these parameters. One of the characteristics of the method is a consideration of the deterioration of the fracture toughness of steel resulting from large cyclic and dynamic straining (Minami and Arimochi, 2001). The strength of steel is increased by pre-straining and dynamic straining, and deterioration of fracture toughness is associated with increased strength. The other characteristic of the method is a correction of CTOD for constraint loss in structural components in large scale yielding (Minami et al., 1999).

The WES2808 procedure may also be applicable to the evaluation of the tensile strain limit against brittle fracture initiation from girth weld flaws in gas pipelines that are subjected to large cyclic deformation. In this paper, modifications of the WES2808 procedure are studied with the aim of applying this standard to gas pipelines. In particular, a fracture assessment method which considers biaxial loading conditions is necessary for pressurized and axial deformed gas pipelines. In this case, the strain used evaluations under WES2808 must be modified because the WES standard uses uniaxial strain. In this study, equivalent plastic strain is used for a strain that affects to the change in strength and fracture toughness by the effects of pre-straining, and a method of estimating equivalent plastic strain under biaxial loading condition is proposed. Furthermore, the applicability of the WES2808 CTOD design curve in fracture assessment of pipeline under biaxial loading condition is investigated. For easy understanding, here, the girth-weld weld metal is assumed to have the same material properties as the base