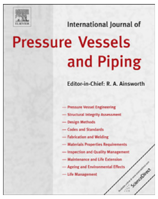
International Journal of Pressure Vessels and Piping 139-140 (2016) 69–76

Contents lists available at ScienceDirect

International Journal of Pressure Vessels and Piping

journal homepage: www.elsevier.com/locate/ijpvp



Study on ratcheting effect of pressurized straight pipe with local wall thinning using finite element analysis

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ARTICLE INFO

Article history:
Available online 11 March 2016

Keywords:
Straight pipe
Ratcheting effect
Local wall thinning
Constitutive model
FEA

ABSTRACT

Ratcheting deformation is studied on straight pipe made of Z2CND18.12 N stainless steel with local wall thinning subjected to constant internal pressure and reversed bending using finite element analysis. The local wall thinning is located at the center of straight pipe, whose geometry is rectangular cross-section. The effect of depth, axial length and circumferential length on the ratcheting behavior of straight pipe is studied in this paper. Three-dimensional elastic-plastic analyses with ANSYS employed Chen–Jiao–Kim (CJK) kinematic hardening model is carried out to evaluate structural ratcheting behaviors. Results indicate that ratcheting strain is along the center of straight pipe extending to the two ends. The ratcheting strain occurs mainly at hoop direction. Axial ratcheting strain is relatively small. The effects of the depth, axial length and circumferential length of local wall thinning on the ratcheting response are discussed by CJK model.

1. Introduction

Carbon steel pipes are commonly used in the piping systems of power plants and chemical industries. Erosion corrosion can cause wall thinning due to high-temperature and high-pressure water and steam flowing at high velocities through these pipes. The piping fittings employed in nuclear power plants and chemical industries play a vital role in safe operation. If the pipelines subjected to internal pressure and cyclic loading, they may face progressive deformation, so-called ratcheting. The ratcheting effect has been considered in several standards, such as ASME [1], KTA [2] and RCC-MR [3]. The aforementioned ratcheting behaviors of straight and elbow pipes have already been extensively studied in the literature [4–7]. A number of investigators discussed experimental and numerical studies on ratcheting, induced by reversed bending, of pressurized straight pipes and elbows made of carbon and stainless steels.

Chen et al. [8] presented an overview of recent progresses in experimental investigation and finite element analysis (FEA) of ratcheting behavior of pressurized piping. Based on experimental and FEA research, ratcheting boundaries have been determined with the final aim of aiding the safety design and assessment of engineering piping structures. The ratcheting behavior of pipelines with wall thinning has also received considerable previous attention in the literature. Miyazaki et al. [9] examined carbon steel pipes with local wall thinning under cyclic pure bending loads to evaluate their low cycle fatigue life. In load controlled tests on these pipes, ratcheting deformation was observed, and the fatigue life of pipes with local wall thinning became lower than that of cracked pipes. The effect of bi-directional loading on the fatigue characteristics of pressurized 90° piping elbows with local wall thinning was investigated by Balan and Redekop [10]. The results provided extensive new information about the fatigue behavior of piping elbow subject to seismic action. Zeinoddini and Peykanu [11] studied the strain ratcheting of steel tubes with a rectangular defect under axial cycling. It was shown that the surface imperfections had a very significant effect on the ratcheting response of the defected tubes. The effects of some factors such as the stress amplitude, wall thinning and the material hardening properties on the ratcheting response of steel tubes were also investigated. Shi et al. [12] studied ratcheting deformation in elbow pipe made of Z2CND18.12 N stainless steel with local wall thinning subjected to constant internal pressure and reversed in-plane bending under load control. Three-dimensional elastic-plastic analyses using ANSYS incorporated with Chaboche [13,14] and Chen-Jiao-Kim (CJK) [15] kinematic hardening models were carried out to

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http://dx.doi.org/10.1016/j.ijpvp.2016.03.005

evaluate structural ratcheting behaviors.

In the present paper, ratcheting behavior of pressurized straight pipe of Z2CND18.12 N austenitic stainless steel with local wall thinning subjected to studies reversed bending was studied. The local wall thinning areas are located at outside surface of the center of straight pipe. Ratcheting simulation is performed by elastic-plastic finite element analyses with ANSYS in which modified Ohno-Wang model (CJK model) are applied. The effect of geometric dimension such as depth, axial length and circumferential angle of local inside and outside wall thinning on the ratcheting behavior of straight pipe was indicated respectively.

2. Kinematic hardening rule

Constitutive model defines the material stress-strain relationship in finite element analysis. The rate independent plasticity models considered in this study has the following common features:

(1) von-Mises yield criterion (yield surface)

$$f = \left[\frac{3}{2}(\mathbf{s}-\boldsymbol{\alpha}):(\mathbf{s}-\boldsymbol{\alpha})\right]^{1/2} - \sigma_y = 0 \tag{1}$$

(2) Strain decomposition

$$d\varepsilon = d\varepsilon^e + d\varepsilon^p \tag{2}$$

$$d\varepsilon^e = \frac{1+\nu}{E}d\sigma - \frac{\nu}{E}tr(d\sigma)I \tag{3}$$

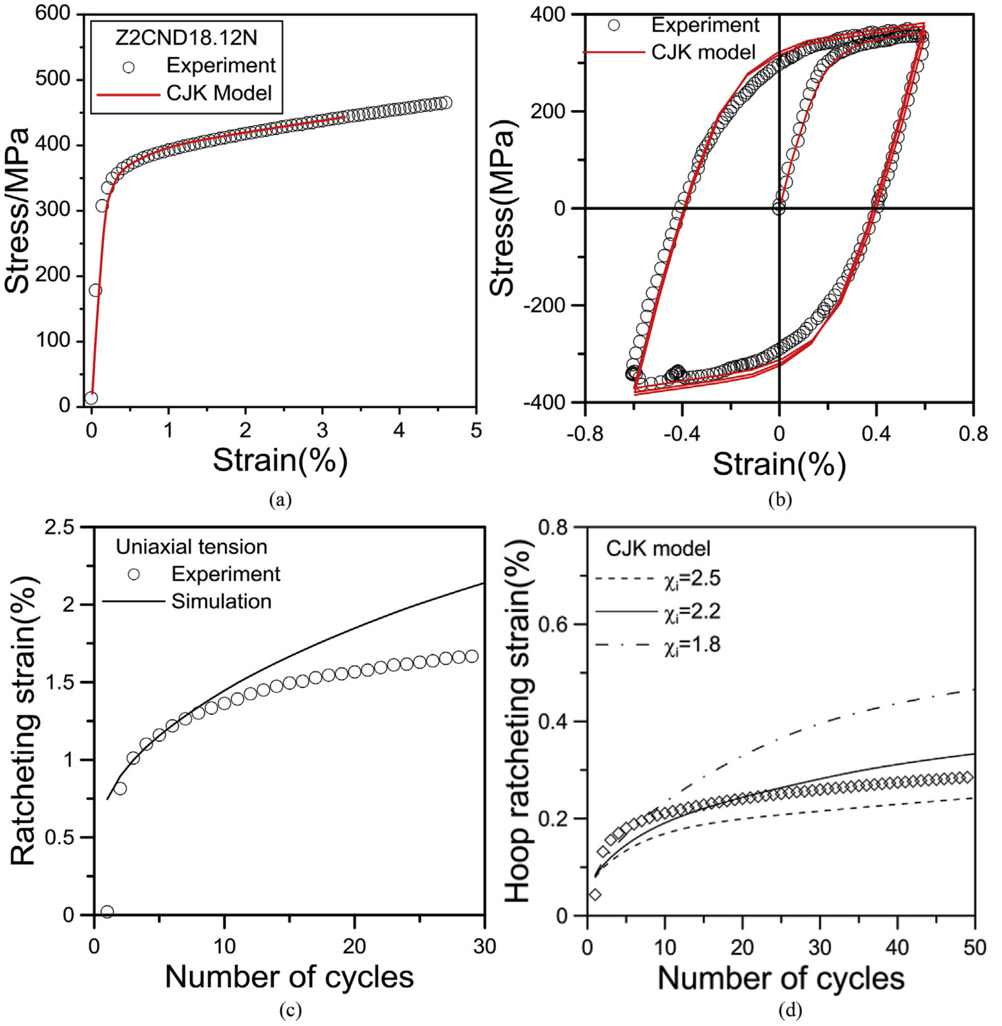
(3) Flow rule

$$d\boldsymbol{\varepsilon}^p = \frac{1}{H}\left\langle \frac{\partial f}{\partial \sigma} : d\sigma \right\rangle \frac{\partial f}{\partial \sigma} \tag{4}$$

$$d\boldsymbol{\varepsilon}^p = \sqrt{\frac{3}{2}}dp[M_1]\frac{\partial f}{\partial \boldsymbol{\sigma}} \tag{5}$$

where σ is the stress tensor, $\boldsymbol{\varepsilon}^e$ the elastic strain tensor, $\boldsymbol{\varepsilon}^p$ the plastic strain tensor, s the deviatoric stress tensor, α the current center of the yield surface in total stress space, σ_y the size of the yield surface, ν the poisson's ratio, E the elastic modulus and H is the plastic modulus.

(4) With the von-Mises yield criterion, the most important feature of a plasticity model in simulating ratcheting



(a) (b)

(c) (d)

Fig. 1. (a) Uniaxial tension; (b) Uniaxial cyclic hysteresis loop; (c) Uniaxial ratcheting strain; (d) Ratcheting strain considering multiaxial parameter.