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CONSTRAINT EVALUATION AND EFFECTS ON J-R RESISTANCE CURVES FOR PIPES UNDER COMBINED LOAD CONDITIONS

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ABSTRACT

Under certain conditions, pipelines may be submitted to biaxial loading situations. In these cases, questions arise about how biaxial loading influence the driving force (i.e.: CTOD, J-integral) of possible presented cracks and how affects the material fracture toughness. For further understanding of biaxial loading effects on fracture mechanics behavior of cracked pipelines, this work presents a numerical analysis of crack-tip constraint of circumferentially surface cracked pipes and SENT specimens using full 3D nonlinear computations. The objective is to examine combined loading effects on the correlation of fracture behavior for the analyzed cracked configurations. The constraint study using the J-Q methodology and the h parameter gives information about the fracture specimen that best represents the crack-tip conditions on circumferentially flawed pipes under combined loads. Additionally, simulations of ductile tearing in a surface cracked plate under biaxial loading using the computational cell methodology demonstrate the negligible effect of biaxial loadings on resistance curves.

INTRODUCTION

Onshore and offshore pipelines can be submitted to loadings beyond yielding during installation and in-service conditions. Heating and cooling cycles, ground movement and frost heave are examples of in-service situations that produce yielding in the pipe metal.

These situations may cause that cracks, formed during fabrication or in service, being loaded under biaxial conditions. Current fracture assessment procedures (i.e. those found in API-579 (2000) and BS-7910 (1999)) are mainly developed for uniaxial loading conditions. However, biaxial loading situations can have a strong effect on the crack driving force (i.e.: CTOD (Wells, 1961), J-integral (Rice, 1968)) and questions arise about how biaxial loading affect applied J-integral and the pipe material toughness. Therefore, further studies for fracture assessment procedures in pipes under combined loadings (i.e.: Bending + Int. Pressure, Tension + Bending + Int. Pressure) are necessaries.

To further understand biaxial loading effects on fracture mechanics of cracked pipelines, this work presents a numerical analysis of crack-tip constraint of circumferentially surface cracked pipes and SENT specimens using full 3D, nonlinear computations. The objective is to examine combined loading effects on the correlation of fracture behavior for the analyzed cracked configurations using the Q (O'Dowd and Shih, 1991, 1992) and h (Brocks and Schmitt, 1993) parameters. The Q parameter measures the deviation of the stress field of the studied geometry from a reference stress solution (i.e. the boundary layer model (Rice, 1967)). On the other hand, the h parameter is defined as the ratio of the hydrostatic stress level ahead of the crack front over the effective Von Mises stress and it characterizes the growth of micro voids in a triaxial stress field. Furthermore, simulations of ductile tearing in a surface cracked plate under biaxial loading using the computational cell methodology allow the study of biaxial effects on tearing behavior.

FE MODELS FOR STATIONARY CRACKS

The numerical computations for the fracture specimens and cracked pipes analyzed in this work are generated using the research code WARP3D (Koppenhoefer et. al., 1994). The analyses utilize an elastic-plastic constitutive model with J_2 flow theory and conventional Mises plasticity using small strain theory. The numerical solutions employ a simple power-hardening model to characterize the uniaxial true stress-strain in the form

$$\frac{\varepsilon}{\varepsilon_0} = \frac{\sigma}{\sigma_0} \qquad \varepsilon \le \varepsilon_0\,; \quad \frac{\varepsilon}{\varepsilon_0} = \left(\frac{\sigma}{\sigma_0}\right)^n \qquad \varepsilon > \varepsilon_0 \tag{1}$$

where σ_0 and ε_0 are the reference (yield) stress and strain respectively, and n is the strain hardening exponent. The finite element analyses consider material flow properties covering a typical line pipe steel with $n = 10$ and $E/\sigma_0 = 500$. Here, E = 210 GPa and ν = 0.3.