Engineering Fracture Mechanics 131 (2014) 128–141

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

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

Constraint analysis of defects in strength mismatched girth welds of (pressurized) pipe and Curved Wide Plate tensile test specimens

M.A. Verstraete *, W. De Waele, R.M. Denys, K. Van Minnebruggen, S. Hertelé

Ghent University, Department of Mechanical Construction and Production, Soete Laboratory, Technologiepark gebouw 903, 9052 Zwijnaarde, Belgium

ARTICLE INFO

Article history:
Received 11 October 2012
Received in revised form 11 May 2014
Accepted 18 July 2014
Available online 4 August 2014

Keywords:
Constraint effects
J-Integral
Plasticity

ABSTRACT

Curved Wide Plate (CWP) specimens are often considered to evaluate the tensile strain capacity of girth weld defected pipelines. However, to date no comparison has been made between the constraint in CWP and (pressurized) pipe specimens. This paper reports on the evaluation of the constraint through three dimensional finite element simulations. At first, it is observed that the internal pressure marginally increases the out-of-plane constraint. Second, the CWP specimens appear to closely represent the constraint in pipe specimens for homogeneous as well as strength mismatched situations. CWP specimens become increasingly conservative to pipe specimens with increasing defect dimensions.

1. Introduction

Transportation pipelines installed in harsh environments might be subjected to displacement controlled loading during operation (e.g. due to landslides). This might result in large (plastic) deformations. The girth welds that connect different pipes unavoidably contain defects, not all of which can be repaired for economical reasons. Accordingly, an assessment procedure is required to determine the allowable defect sizes and/or tensile strain capacity. The determination of these limits can be performed by means of full scale testing. Next to axial tension these tests should incorporate internal pressure, as the resulting biaxial loading condition is known to be strongly detrimental to crack driving force [1,2]. However, such tests require high test capacities and are time consuming.

Alternatively, sub-scale test specimens can be considered. Since the 1980s, Curved Wide Plate (CWP) testing has been widely used to assess defected girth welds [3–5]. However, these tests do not reflect the actual geometry nor the loading conditions; with the main drawback that internal pressure is lacking. Nevertheless, application of a so-called pressure correction factor allows estimation of the tensile strain capacity for full scale pipes using the results of CWP testing [6–8]. Such correction however implicitly assumes that the apparent toughness is comparable in both CWP and (pressurized) pipe specimens.

To verify the assumption with respect to the apparent toughness, this study evaluates the stresses ahead of the crack tip based on an extensive set of three dimensional finite element simulations. These stresses are known to influence the apparent toughness due to the constraint developing ahead of the crack tip. Several theoretical frameworks are available to characterize this constraint level [9–11]. In this study a constraint analysis is carried out based on the two-parameter

* Corresponding author.
E-mail address: Matthias.Verstraete@UGent.be (M.A. Verstraete).

http://dx.doi.org/10.1016/j.engfracmech.2014.07.018
0013-7944/

Nomenclature

a	defect depth
b_0	initial remaining ligament thickness
c	half defect arc length
D	pipe diameter
E	Young's modulus
h	stress triaxiality
J	J-integral
n	strain hardening exponent
Q	constraint parameter (uniaxial)
Q_m	constraint parameter (triaxial)
ΔQ	variation of Q-parameter
$\bar{r}$	normalized distance ahead of the crack tip
t	pipe wall thickness
Y/T	yield-to-tensile ratio
ε	true strain
θ	angle perpendicular to the crack
φ	angle parallel to the crack
σ	true stress
σ_0	yield strength
σ_e	Von Mises equivalent stress
σ_{hoop}	hoop stress
σ_{ij}	stress in ij-direction
σ_m	hydrostatic stress
%MM	yield strength mismatch

J–Q framework developed by Shih and O'Dowd in the early 1990s [12,13], which is well accepted for situations with pronounced plasticity [14]. In addition, the stress triaxiality parameter h, defined as the ratio between the hydrostatic stress and Von Mises equivalent stress, is evaluated ahead of the crack tip [15,16]. The equivalence between the constraint parameters Q and h has been reported in literature [17,18], though the stress triaxiality is assumed to have a higher physical relevance in case of ductile failure. These constraint analyses are first performed for homogeneous specimens. Subsequently, the influence of weld strength mismatch is considered, as strength overmatching welds are generally required for plastically deforming pipelines.

The remainder of this paper is structured as follows; first, a description of the test specimen geometries and finite element models is provided in paragraph 3. Second, in paragraph 4 an evaluation is made of the constraint evolution in (pressurized) pipes and CWP specimens. Conclusions are given in paragraph 5.

2. Methodology

This paragraph provides a description of the simulated test specimen geometries. Second, the developed finite element models and associated assumptions are outlined. The third subsection elaborates on material properties and simulation of weld strength mismatched configurations. The final subsection provides a brief description of the constraint calculations presented in this paper.

2.1. Geometry of Curved Wide Plate and pipe specimens

The simulated pipe specimens are characterized by their outer diameter (D) and wall thickness (t) (Fig. 1a). Within the set of simulations performed, the wall thickness was fixed at 15 mm. The diameter is varied between 762 mm (30″) and 1270 mm (50″). The length of the simulated pipe specimens equals four times their diameter, which suffices to yield results independent from the boundary conditions [19].

In practice, CWP specimens are extracted from pipe specimens. Accordingly, these have a curvature defined by the pipe's diameter and have the same wall thickness. The total length of the CWP specimens equals 1200 mm, whereas the prismatic section is 900 mm long and 300 mm wide (Fig. 1b). All other geometrical properties are in agreement with the UGent Guidelines for CWP testing [3].

The specimens have constant depth surface breaking defects with an end-radius equal to the defect depth. The crack geometry is furthermore characterized by the defect depth (a) and defect arc length ($2c$). Unless otherwise specified, these