Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 2 (2016) 777–784

Structural Integrity Procedia

www.elsevier.com/locate/procedia

21st European Conference on Fracture, ECF21, 20-24 June 2016, Catania, Italy

Two-parameter fracture characterization of a welded pipe in the presence of residual stresses

S. Abolfazl Zahedi*, Andrey Jivkov

School of Mechanical, Aerospace and Civil Engineering, The University of Manchester, Manchester, M13 9PL, UK

Abstract

In this paper two-parameter fracture characterization of elastic and elastic-plastic stress/strain field around a crack front is presented for a welded pipe component containing a circumferential through-thickness crack. A macro function programmed in PYTHON is used to compute the constraint parameters (T-stress, T_z and Q factors) of the specimen in the open source finite element package Code_Aster. Data obtained from literature was employed to support three-dimensional finite element models developed in this research to study the impact of high magnitude repair-weld residual stresses. Complete distributions of the T-stress, T_z and Q-factors were obtained along a 3D crack front in the presence of residual stresses. The effects of stresses (residual and operational) on the constraint parameters are studied. It is shown that a two-parameter methodology provides effective characterization of three dimensional elastic–plastic crack tips constraint.

Keywords: constraint parameters; T-stress; T_z-factor; Q-factor; residual stress

1. Introduction

Residual stresses are present in most mechanical or thermal components due to the fabrication methodology, such as welding. They attract considerable attention in engineering applications, because of their impact on part distortion, service performance and the costs associated with failures (Gannon et al., 2010). Therefore, it is necessary to understand the combined effect of mechanical loading and residual stresses on the fracture of structures in order to provide a more accurate structural integrity assessment. The prediction of crack initiation and propagation requires

* Corresponding author. Tel.: +44-0161-306-2737; fax: +44-0161-306-2737.
E-mail address: Abolfazl.Zahedi@manchester.ac.uk

Copyright © 2016 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer review under responsibility of the Scientific Committee of ECF21.
10.1016/j.prostr.2016.06.100

taking into account the three-dimensional nature of the crack-front stress field, which is depended on the loading conditions and crack geometry. It is well known that the elastic or plastic fracture mechanics by considering the stress intensity factor K or the J-integral parameters works well only under high constraint conditions. Differently, constant stress contributions acting over a longer distance from the crack tip affect fracture mechanics properties (Kim and Paulino, 2003).

For cracks under low constraint conditions, the crack-tip stress field deviates from small scale yielding (SSY) solution. To quantify this effect for elastic or elastic-plastic behaviour, additional parameters to the stress intensity factor K or the J-integral are required. In a two-parameter approach, the first parameter measures the degree of crack-tip deformation, as characterized by K or J-integral and the second parameter characterizes the degree of crack tip constraint. In elastic materials this is the second distance-independent term of the Williams expansion for stresses, namely the T-stress in mode I and mixed-mode in-plane loading. This parameter has a significant effect on the size and shape of the plastic zone developing around the crack tip. For three-dimensional cracked bodies, the constraint effect through the thickness is evaluated by the T_z-factor. In elastic-plastic materials a non-dimensional Q-factor quantifies the level of deviation of a stress/strain field from a SSY solution.

The application of two-parameter fracture mechanics, K-T or J-Q, to include the constraint effect in the engineering assessment procedure is becoming more and more established. Meanwhile, the effects of residual stresses on the crack driving forces, and the stress field near the crack-tip in integrity assessments are still unexplored in the open literature. Hill and Panontin (1998) investigated the effects of residual stresses on ductile and brittle crack growth initiation in a pipe with a circumferential crack, and confirmed that residual stresses contribute to the crack driving forces. Hill and Yau (2000) studied the effects of thermo-mechanical loading and residual stresses on crack-tip constraints. Liu et al. (2008) computed the crack-tip constraint for single edge notched specimens subject to an external bending load in a condition of one-dimensional residual stress field. Farhani and Sattari-Far (2011) presented the effects of residual stresses on crack behaviour in a large disk shaped model. All these studies were limited to a small number of crack geometries and loading cases in the presence of residual stresses. It is of practical interest to consider a body with a more complex shape under primary and secondary stresses to calculate the fracture constraint parameters along the crack front.

In this study T-stress, T_z and Q factors are computed for a welded pipe component made with austenitic stainless steel containing a circumferential through-thickness crack. Since welds made from this material cannot be normally post-weld heat treated before entering service, the pipe will contain weld residual stresses. A macro function programmed in PYTHON is used to compute constraint parameters (T-stress, T_z and Q factors) in the open source finite element package Code_Aster.

2. Theory

2.1. Computation of T-stress and T_z factor

Based on isotropic linear elasticity theory, when an elastic cracked body is subjected to external forces (see Fig.1) the stress field in the vicinity of a crack tip can be expressed by Williams' expansion. The stresses near the crack-tip can be written as follows (Novotný, 2012):

$$\begin{aligned}
\sigma_{rr} &= \frac{K_I}{\sqrt{2\pi r}}\left(\frac{5}{4}\cos\frac{\theta}{2}-\frac{1}{4}\cos\frac{3\theta}{2}\right)+\frac{K_{II}}{\sqrt{2\pi r}}\left(-\frac{5}{4}\sin\frac{\theta}{2}+\frac{3}{4}\sin\frac{3\theta}{2}\right)+T cos^2\theta \\
\sigma_{\theta\theta} &= \frac{K_I}{\sqrt{2\pi r}}\left(\frac{3}{4}\cos\frac{\theta}{2}+\frac{1}{4}\cos\frac{3\theta}{2}\right)+\frac{K_{II}}{\sqrt{2\pi r}}\left(-\frac{3}{4}\sin\frac{\theta}{2}+\frac{3}{4}\sin\frac{3\theta}{2}\right)+T sin^2\theta \\
\sigma_{r\theta} &= \frac{K_I}{\sqrt{2\pi r}}\left(\frac{1}{4}\sin\frac{\theta}{2}+\frac{1}{4}\sin\frac{3\theta}{2}\right)+\frac{K_{II}}{\sqrt{2\pi r}}\left(+\frac{1}{4}\cos\frac{\theta}{2}+\frac{3}{4}\cos\frac{3\theta}{2}\right)-T sin\theta\cos\theta,
\end{aligned} \tag{1}$$