Marine Structures 53 (2017) 148–163

Contents lists available at ScienceDirect

Marine Structures

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

Stress intensity factors for semi-elliptical surface cracks in plate-to-plate butt welds with parallel misalignment of same thickness

H.S. Zhao*, S.T. Lie, Y. Zhang

School of Civil & Environmental Engineering, Nanyang Technological University, 50 Nanyang Avenue, 639798 Singapore

ARTICLE INFO

Article history:
Received 17 June 2016
Received in revised form 28 December 2016
Accepted 16 February 2017

Keywords:
Finite element analyses
Misaligned butt welds
Regression analyses
Surface crack

ABSTRACT

A set of fatigue and fracture assessment equations had been incorporated into British Standard 7910:2013 (BS 7910:2013) to estimate the effect of misalignment for various geometric configurations containing a surface crack. In this study, extensive 3-D finite element (FE) analyses are carried out to determine the dimensionless stress intensity factors (Y) at the crack deepest point and crack ends of plate-to-plate butt welds with parallel misalignment of same thickness. In comparison to BS 7910:2013, it is observed that the assessment equations underestimate the Y values for shallow cracks and overestimate the corresponding values for deeper cracks with percentage differences in values being as high as 82% and 12%, respectively. New Y equations for misaligned butt welds are proposed using multiple regression analyses.

1. Introduction

When plates or shells are welded together, there is invariably some degree of misalignment such as centreline offset, angular or both. The misalignment induces a local bending stress, increasing the risk of brittle fracture and shortening the fatigue life of a welded joint [1]. Therefore, it is very important to be able to assess the effect of misalignment on the fatigue and fracture strength of welded joints. Maddox [2] investigated the influence of misalignment on the fatigue strength of transverse butt welds. He found that fatigue test results for misaligned butt welds could be associated with the corresponding results of aligned butt welds by taking into account the stress concentration factor (SCF) induced by misalignment based on the superposition principle. This approach was employed by Andrews [3] to analyze a more complex geometry, the transverse load-carrying cruciform joint with centerline offset misalignment, and the following specific assessment expression is used,

$$K_I = Y_a \sigma_a \sqrt{\pi a} + (k_m - 1) Y_b \sigma_a \sqrt{\pi a} \tag{1}$$

where K_I is the Mode-I stress intensity factor (SIF), Y_a and Y_b are the geometry factors for the aligned joints subjected to axial and bending loading, σ_a is the applied axial stress, a is the crack depth, k_m is the SCF induced by misalignment, and it is defined as

* Corresponding author.
E-mail address: HZHAO006@e.ntu.edu.sg (H.S. Zhao).

http://dx.doi.org/10.1016/j.marstruc.2017.02.005
0951-8339/

$$k_m = 1 + \frac{\sigma_s}{\sigma_a} \quad (2)$$

where σ_s is the maximum induced bending stress due to misalignment. Obviously, the effect of misalignment on SIFs is introduced into Eq. (1) based on using k_m. Therefore, determining the SCF equations for various geometric configurations and types of misalignment is significant. In the past several decades, considerable research [4–12] has been conducted to develop the SCF equations, and these equations have been incorporated into several codes of practice such as DNV-RP-C203 [13] and BS 7910:2013 [14].

BS 7910:2013 [14] includes a set of fatigue and fracture assessment equations for cracked butt welds with misalignment. In these equations, the Newman and Raju equation [15] for a semi-elliptical surface crack in a plain plate is chosen as the base stress intensity equation. The effect of the weld toes in welded joints is considered using a weld toe magnification factor M_k, and the SCF equations are taken into account for misalignment. Therefore, these assessment equations are actually determined based on the superposition principle. In this study, finite element (FE) models for plate-to-plate butt welds with parallel misalignment of same thickness are generated by the mesh generator and extensive 3-D FE analyses are carried out to determine directly the required SIFs. By comparing the FE results with BS7910:2013 [14], it is found that the assessment equations underestimate the SIFs for shallow cracks and overestimate the corresponding values for deeper cracks. Therefore, a set of new SIF equations for cracked butt welds with misalignment are built up using multiple regression analyses.

2. Scope of parametric numerical study

The various parameters used in this study are chosen based on the works done by Lie et al. [16] and the AWS D1.1:2000 recommendations [17]. The SIF equations mentioned in the BS7910:2013 [14] are usually valid for a sharp weld toe where the weld toe radius is taken to be zero, and Lazzarin and Livieri [18] proposed that the sharp weld toe assumption is more realistic because the toe radius is difficult to measure and is affected by a large scatter. Therefore, the present study solely focuses on the sharp weld toe cases. Considering that butt welds should be made with minimum face reinforcement not exceeding 3 mm and the weld surface needs to be flushed in many cases, butt welds with flushed surfaces are only analysed, which means that the weld reinforcement (R) is zero. The surface crack located at the weld toe is perpendicular to the main plate face as indicated in Fig. 1. Four basic parameters, namely, crack depth ratio (a/T), crack aspect ratio (a/c), width ratio of weld bead (L/T) and centreline offset ratio (e/T) are included in the parametric study (please refer to Fig. 1 for notations).

2.1. Details of crack and weld parameters

As outlined in Table 1, 11 different crack depth ratios are analysed, varying from a very shallow crack depth ratio of 0.05 to a deep crack depth ratio of 0.9. For all the analyses, the plate thickness (T) is kept constant and the crack depth (a) is gradually changed to get the required crack depth ratio. The crack aspect ratios vary from 0.1 to 1.0. Width ratios of weld beads of 0.2, 0.8, 1.4 and 2.0 are applied based on AWS D1.1:2000 recommendations [17]. The wide range of parameters practically covers the most commonly used butt weld configurations. As for the centreline offset, a typical value used in many fabrication standards is $e = 0.15T$ or maximum 3–4 mm [12]. Hence, centreline offset ratios (e/T) of 0.00, 0.05, 0.10 and 0.15 are employed in the present study.

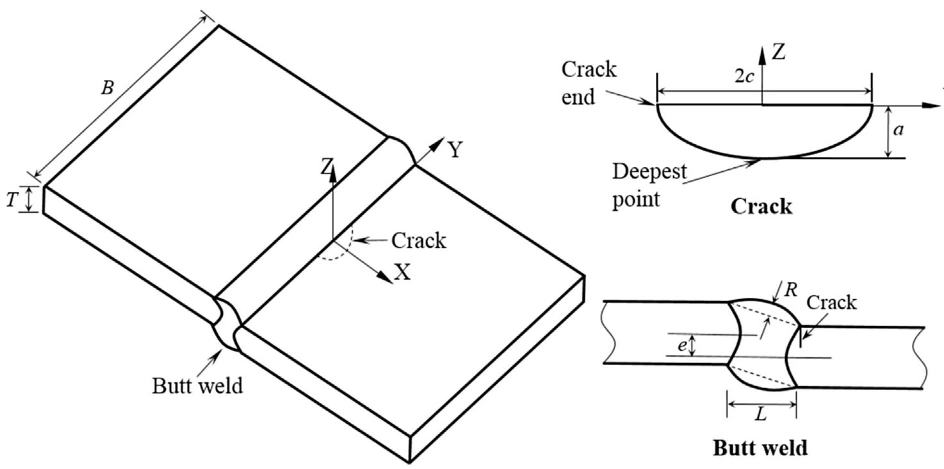

Fig. 1. Nomenclature of parameters of butt welds with parallel misalignment of same thickness.