International Journal of Fatigue 77 (2015) 28–40

Contents lists available at ScienceDirect

International Journal of Fatigue

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

Numerical modelling of plane strain plasticity induced crack closure effects for bimaterial interfacial cracks

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ARTICLE INFO

Article history:
Received 10 December 2014
Received in revised form 25 February 2015
Accepted 1 March 2015
Available online 10 March 2015

Keywords:
Plasticity induced crack closure
Plane strain
Finite element modelling
Bimaterial interfacial cracks

ABSTRACT

The effects of plane strain plasticity induced crack closure on fatigue cracks located at the interface of dissimilar steel materials are presented using finite element modelling. Based on the study, it has been observed that bimaterial cracks produced unsymmetrical residual plastic strains and crack profiles in the crack wakes. It is seen that Young's modulus and yield stress mismatch have profound effects on the development of unsymmetrical residual plastic strain and crack profiles, whereas the effect of Poisson's ratio is insignificant. However, it has been found that for the material properties considered, low value of crack closure levels have been identified.

1. Introduction

The study of interface fracture is important since the strength of structural components of different components bonded together is mostly governed by the behaviour of the interface, which may be weakened by the development of flaws or cracks along the bonding (e.g. [18,7]). In welded structures which are widely used in the engineering industry, interfacial cracks/defects can occur in the Heat Affected Zones (HAZ) at the junction of the base and weld materials (e.g. [8,9]). In contrast to homogeneous/isotropic material; the fracture mode of cracks lying in the interface of dissimilar materials is inherently mixed, and fracture modes are coupled. Due to the mismatch in the elastic properties of the materials on either side of the interface, and possible non-symmetric (or mixed mode) loading and geometry, an interface crack experiences both tensile and shear modes even if the remote loading corresponds to Mode I [25,6,16,5,10,19,26]. Whilst several studies on bimaterial interface cracks are reported in the literature, most of them have focused on the effects of 'monotonic'loading cases. The importance of extending to cyclic (fatigue) loading cases is pertinent considering the fact that most engineering structures are fatigue critical under real service conditions. In the literature, various crack closure studies have been reported both experimentally and numerically for homogenous (or single- or mono-) material bodies (e.g. [23,12,20,21]); however to the best of the author's knowledge only Wei and James [24] reported plasticity induced crack closure (PICC) effects for interfacial cracks in bi-material specimens under 'plane stress' conditions using finite element (FE) techniques. Initial studies [15,20,21] on the effects of plane strain PICC on single-material bodies using FE methods showed low closure levels with crack closure mostly dominated by pre-crack contact. Hence in this paper an attempt has been made to study the effects of cracks located at the interface of dissimilar material combinations such as, (1) different base materials, (2) base and weld materials, and (3) weld and HAZ materials, as applied to welding of two steels of different strengths, under 'plain strain' conditions. More specifically, the effect of differences/mismatch in Young's modulus, yield stress, and Poisson's ratio; thickness; thickness and yield stress for cracks lying in the interface of two base, base and weld, and base and HAZ materials respectively have be analysed. The effects of material mismatch are presented in the form residual plastic strains, deformed shapes and crack closure levels.

2. Finite element modelling

2.1. Problem description

Three geometries have been chosen for the present analyses. Fig. 1 shows a conventional rectangular center-cracked plate (CCP) with crack lying at the interface of dissimilar materials (Materials 1 and 2). A conventional rectangular CCP subjected to remote tension (σ) has been considered for the FE analyses. Fig. 1 shows the geometry, along with the relevant boundary

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http://dx.doi.org/10.1016/j.ijfatigue.2015.03.001
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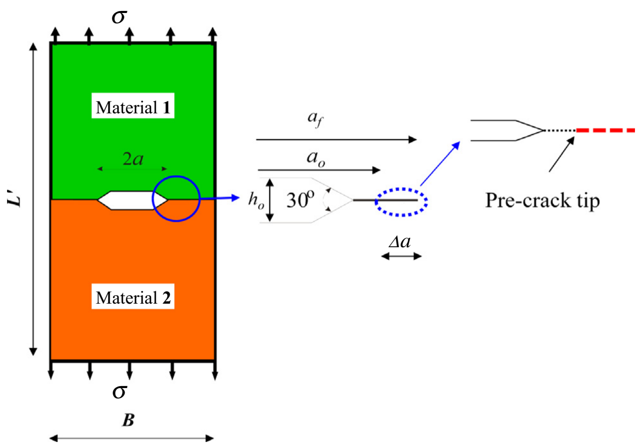

Fig. 1. Schematic diagram of the geometry and loading of the center cracked panel (CCP) specimen showing an interface crack located at the interface of two different materials Material 1 and Material 2 (After [15,20,21]).

conditions. The geometry is similar to that considered by [15,20,21]), with the dimensions being, length, $L' = 250.0$ mm, width, $B = 75$ mm, half initial crack length, $a_o = 8.0$ mm, half notch length, $a = 7.5$ mm, notch angle of 30°, notch width, and $h_o = 1.0$ mm. Three types of interface cracks have been considered in the present study *viz*., interface cracks located at the interface of (1) different base materials, (2) base and weld materials, and (3) weld and HAZ materials. Schematic representations of the geometry, loading and location of interface cracks located at the interface of, (1) two different base materials (B1B2 panel), (2) weld and base materials (B1WB1 panel), and (3) weld and HAZ materials (B1WH panel) are shown in Figs. 2–4 respectively. Thicknesses of weld (W) and HAZ (H) have also been varied (W or $H = 3.6$ mm, 6.6 mm, 9.6 mm) to analyse the effect of thickness (W and H). Baseline loading of $\Delta K = 12.0$ MPa m$^{1/2}$ (where $\Delta K = K_{max} - K_{min}$; K_{max} and K_{min} are the maximum and minimum stress intensity factors respectively), corresponding to typical Paris law conditions, with a zero load ratio, $R = 0.0$ has been considered for the crack closure investigation. Although, it is theoretically possible to consider high load ratios i.e. $R > 0.0$, this condition is not considered as yield stress values of some of the constituent materials are relatively

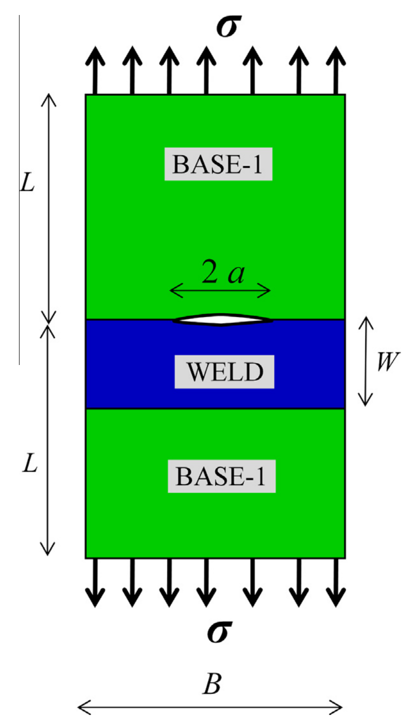

Fig. 3. Schematic diagram of the geometry and loading of a mismatched panel with an interface crack located at the interface of weld and base materials (B1WB1 panel).

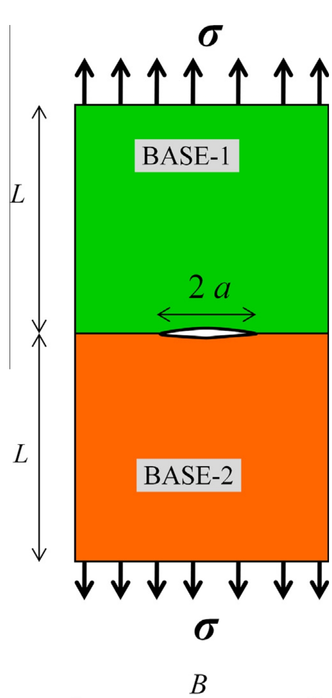

Fig. 2. Schematic diagram of the geometry and loading of a mismatched center cracked panel with an interface crack located at the interface of two different base materials (B1B2 panel).

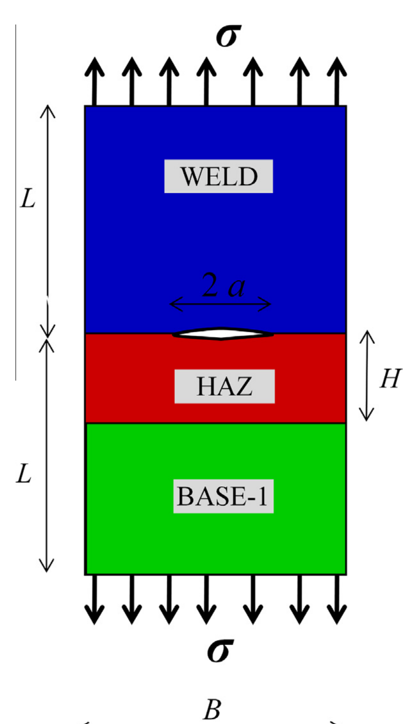

Fig. 4. Schematic diagram of the geometry and loading of a mismatched panel with an interface crack located at the interface of HAZ and weld materials (B1HW panel).