ARTICLE IN PRESS

Engineering Fracture Mechanics xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

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

Stress intensity factor solutions for adhesive-bonded lap-shear specimens of magnesium and steel sheets with and without kinked cracks for fatigue life estimations

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ARTICLE INFO

Article history:
Received 9 May 2014
Received in revised form 24 August 2014
Accepted 2 September 2014
Available online xxxx

Keywords:
Adhesive-bonded joint
Dissimilar joint
Lap-shear specimen
Stress intensity factor solution
Kinked crack
Fatigue life estimation

ABSTRACT

In this paper, stress intensity factor solutions for adhesive-bonded lap-shear specimens of magnesium alloy AZ31 and hot-dip-galvanized (HDG) mild steel sheets with and without kinked cracks are investigated for fatigue life estimations. First, the kinked fatigue crack failure mode of the adhesive-bonded lap-shear specimens is briefly reviewed. Then, the analytical global J integral and effective stress intensity factor solutions for main cracks in lap-shear specimens of three dissimilar sheets under plane strain conditions are developed based on the beam bending theory. The global effective stress intensity factor solutions for the main cracks in the lap-shear specimens from the corresponding finite element analyses are then presented and validated by the analytical solutions. Next, the local stress intensity factor solutions for kinked cracks with the experimentally observed kink angle as functions of the kink length from the corresponding finite element analyses are presented and the computational solutions are also compared with the analytical solutions at small kink lengths. The results indicate that the computational local stress intensity factor solutions for kinked cracks approach to the analytical solutions as the kink length decreases to a small value and the kinked crack is under dominant mode I loading conditions. The computational results also indicate that the local stress intensity factor solutions at a small kink length of microstructural significance may be used as the stress intensity factor solutions for zero or near zero kink length for fatigue life estimations when the computational results are not available. The computational local stress intensity factor solutions are then adopted to estimate the fatigue lives of the lap-shear specimens based on a kinked crack growth model and available material constants for the Paris law. The fatigue life estimations are lower than the experimental results. However, the general trend of fatigue life estimations agrees with that of the experimental results.

1. Introduction

Lightweight materials such as advanced high strength steels, aluminum, and magnesium alloys have been replacing the traditional steel in the automotive industry to reduce the vehicle weight. Since magnesium alloys are much lighter than the steels commonly used in vehicles, using magnesium alloys could result in a substantial weight reduction. One of the major

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http://dx.doi.org/10.1016/j.engfracmech.2014.09.002
0013-7944/

Please cite this article in press as: Lai W-J, Pan J. Stress intensity factor solutions for adhesive-bonded lap-shear specimens of magnesium and steel sheets with and without kinked cracks for fatigue life estimations. Engng Fract Mech (2014), http://dx.doi.org/10.1016/j.engfracmech.2014.09.002

Nomenclature

HDG	hot-dip-galvanized
b	specimen width
L	sheet length
t_u	thickness of sheet u
t_{l1}	thickness of sheet $l1$
t_{l2}	thickness of sheet $l2$
V	specimen overlap length
w	bonded width
E	Young's modulus
G	shear modulus
ν	Poisson's ratio
σ	normal stress
J	J integral
W	strain energy density function
W_j	strain energy density function for sheet j
Γ	J integration contour
ds	differential arc length for the contour Γ
$\mathbf{n}$	unit outward normal
n_x	x component of the unit outward normal $\mathbf{n}$
$\mathbf{T}$	traction vector
$T_i(=\sigma_{ij}n_j)$	components of the traction vector $\mathbf{T}$
$\mathbf{u}$	displacement vector
u_i	components of the displacement vector $\mathbf{u}$
σ_{ij}	stress components
ε_{ij}	strain components
E'	Young's modulus under plane stress or plane strain conditions
σ^*	normal structural stress to satisfy the equilibrium, and continuity of the strain and strain gradient
δ_u	ratio of the sheet u thickness to the total sheet thickness
δ_{l1}	ratio of the sheet $l1$ thickness to the total sheet thickness
δ_{l2}	ratio of the sheet $l2$ thickness to the total sheet thickness
t	total thickness of sheets u, $l1$ and $l2$
η_{u1}	modulus ratio of sheet u to sheet $l1$
η_{12}	modulus ratio of sheet $l1$ to sheet $l2$
D	constant defined in Eq. (39)
N_j	constants defined in Eqs. (18)–(38)
C_{ijmnl}	constants defined in Eq. (40)
θ	angle between the loading direction and the x direction
d	distance from the load application point to the nearest main crack tip
F	applied load
K_e	global effective stress intensity factor
$\mathbf{K}(=K_1+iK_2)$	complex stress intensity factor for an interface crack
σ_y	normal stress in the y direction
τ_{xy}	shear stress with respect to the x and y directions
t_c	characteristic length
r	small distance ahead of an interface crack tip
ε	bimaterial constant
κ_u	constant defined in Eq. (49)
κ_{l1}	constant defined in Eq. (50)
κ_{l2}	constant defined in Eq. (52)
E^*	constant defined in Eqs. (54) and (55)
K_I, K_{II}	conventional mode I and II stress intensity factors
$\mathbf{K}^A\left(=K_1^A+iK_2^A\right)$	complex stress intensity factor for an interface crack obtained from ABAQUS
F_1, F_2, F_e	dimensionless geometric functions for main cracks
a	kink length
φ	kink angle
k_I, k_{II}	local stress intensity factors
k_e	local effective stress intensity factor
α, β	Dundurs' parameters
c, d	complex functions of α, β and φ