Engineering Fracture Mechanics 166 (2016) 82–96

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

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

Experimental evaluation of the effect of overloads on fatigue crack growth by analysing crack tip displacement fields

J.M. Vasco-Olmo *, F.A. Díaz

Universidad de Jaén, Escuela Politécnica Superior de Jaén, Departamento de Ingeniería Mecánica y Minera, Campus Las Lagunillas, Jaén 23071, Spain

A R T I C L E I N F O

Article history:
Received 1 April 2015
Received in revised form 25 July 2016
Accepted 29 August 2016
Available online 30 August 2016

Keywords:
Fatigue crack
Crack shielding
Overload
Stress intensity factor
Digital image correlation

A B S T R A C T

In this work, the shielding effect on growing fatigue cracks under different overload levels is evaluated by estimating stress intensity factors from the analysis of crack tip displacement fields measured by digital image correlation (DIC). A novel model called CJP is implemented to characterise crack tip displacement fields. The retardation effect induced by overloads is quantified from the calculation of the crack opening load. Moreover, a compliance based method is employed to compare and validate those results obtained by DIC. Results show a good level of agreement, highlighting that CJP model is a powerful tool to evaluate fracture mechanics problems.

1. Introduction

Providing quantitative answers to problems related to contained cracks in mechanical elements has been an interesting topic of research since long time. In particular, fatigue cracks have been one of the main sources of structural failure in real service structures, where fracture mechanics has contributed to a better understanding of fatigue crack growth mechanisms. However there are still some issues that remain unresolved or misunderstood, one of these aspects is fatigue crack shielding phenomenon. This misunderstanding comes mainly from problems in its measurement and interpretation [1].

Fatigue crack growth at constant amplitude loading is reasonably well-understood through the shielding mechanisms at the vicinity of the crack tip. However, there is controversy about the possible mechanisms that can explain the retardation effect induced on fatigue crack growth due to the application of overloads. Three possible mechanisms have been proposed to explain retardation following an overload [2]. The first mechanism establishes plasticity-induced crack closure as retardation effect in the study of overloads [3,4]. The second retardation mechanism relapses on crack tip blunting [5]. Finally, residual compressive stresses are established as the third retardation mechanism in the study of overloads [6]. Plasticity-induced crack closure decreases fatigue crack growth rate by reducing the effective stress intensity factor range due to the contact between crack surfaces as the crack starts closing in a premature way [2]. Perhaps the most compelling evidence in favour of the closure argument is the phenomenon of delay retardation. That is, retardation generally does not occur immediately following the application of an overload. In some cases, the crack growth rate actually accelerates for a brief period after the overload. Closure mechanism provides a plausible explanation for the momentary acceleration of crack growth rate following an overload. If closure is occurring during constant amplitude loading, the effective stress intensity factor range is lower than the nominal stress intensity factor range and the crack growth rate is less than it would be in

* Corresponding author.
E-mail address: jvasco@ujaen.es (J.M. Vasco-Olmo).

http://dx.doi.org/10.1016/j.engfracmech.2016.08.026
0013-7944/

Nomenclature

$A', \ldots, F'$	coefficients on CJP model for describing crack tip displacement fields
a	crack length
a_0, b_0	terms accounting for the horizontal and vertical rigid body translation
c_0	term accounting for the rigid body rotation
E	Young's modulus
F_{Ax}, F_{Ay}	reactions forces to the applied remote load
F_C	contact force between crack flanks
F_{Px}, F_{Py}	forces induced by the compatibility requirements on the elastic-plastic boundary
F_S	shear force on the elastic-plastic boundary
F_T	force due to the T-stress
G	shear modulus
i	square root of -1
j	jth collected data point
K_{cl}	closing stress intensity factor
K_F	opening mode stress intensity factor in CJP model
K_I	mode I stress intensity factor
K_{op}	opening stress intensity factor
K_R	retardation stress intensity factor
K_S	shear stress intensity factor
R	ratio between the minimum and the maximum applied load
r, θ	polar coordinates of the collected data points
s^2	variance of the mathematical fitting
T	T-stress
t	specimen thickness
u, v	horizontal and vertical displacements
W	specimen width
z	complex coordinate of the collected points around the crack tip
ΔK_{eff}	effective stress intensity factor range
ΔK_{nom}	nominal stress intensity factor range
ΔP	applied loading range
μ	mean of the mathematical fitting
κ	function of Poisson's ratio
ν	Poisson's ratio

the absence of closure. When an overload is applied, closure does not occur immediately following the overload, so the crack growth rate is momentarily higher than it was prior to the overload. In addition, the overload produces a larger plastic stretch in the wake of the crack tip as the fatigue crack propagates through the overload plastic zone. The contact of the fracture surfaces causes an enhancement in the level of plasticity-induced crack closure in the post-overload regime which promotes a retardation of crack growth rate.

In the study of fracture mechanics problems, the analysis of the stress or displacement fields at the vicinity of the crack tip plays a significant role. Recently, full field experimental optical techniques such as photoelasticity [7,8] and thermoelasticity [9,10] have contributed to a better understanding of the different fatigue mechanisms and the retardation effect that can be induced during fatigue crack growth. In addition, digital image correlation (DIC) seems to be a very suitable technique for quantifying crack shielding phenomenon since displacement fields around the crack tip can be quantified with high level of accuracy [11]. Thus, experimental analysis of stress or displacement fields around a fatigue crack tip together with the experimental determination of stress intensity factors (SIFs) have constituted a major area of research for many years. Traditionally, it has been known in Linear Elastic Fracture Mechanics (LEFM) [12] that displacement fields at the vicinity of the crack tip can be characterised by SIFs. New methodologies for the calculation of SIFs from the analysis of the crack tip displacement fields have been developed [13–15]. Some works were based on Williams's expansion series [13,14] and others on Muskhelishvili's complex potentials [15]. All these methodologies were based on the Multi-Point Over-Deterministic Method (MPODM) developed by Sanford and Dally [16] for SIF calculation. Recently, special interest has been focused on the development of a novel mathematical model named CJP to describe crack tip stress/displacement fields. This model [17–19] considers the crack shielding effect on the elastic stress field induced by plasticity generated around growing fatigue cracks.

Although DIC is globally accepted as a powerful technique for the analysis of fatigue and fracture problems, relatively little work has been done on the evaluation of crack shielding in growing fatigue cracks. The use of DIC for studying fracture mechanics problems started in 1980s, therefore most of the research work developed on the evaluation of fatigue crack shielding is quite recent. The first application of DIC to the measurement of fatigue crack closure was published by Sutton