Theoretical and Applied Fracture Mechanics 69 (2014) 63–70

Contents lists available at ScienceDirect

Theoretical and Applied Fracture Mechanics

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

Load sequence effects on fatigue crack growth in notched tubular specimens subjected to axial and torsion loadings

Maksym Gladskyi [a], Ali Fatemi [b,*]

[a] Department of Manufacturing Engineering, Institute of Mechanical Engineering, National Technical University of Ukraine "Kyiv Polytechnic Institute",
37 Peremogy Avenue, Kyiv 03056, Ukraine
[b] Mechanical, Industrial and Manufacturing Engineering Department, The University of Toledo, 2801 West Bancroft Street, Toledo, OH 43606, USA

ARTICLE INFO

Article history:
Available online 6 December 2013

Keywords:
Fatigue crack growth
Load sequence effect
Notch effect
T-stress effect

ABSTRACT

Fatigue crack growth behavior of tubular specimens with a through thickness circular hole made of a carbon steel subjected to axial and torsional loads was investigate. Loading sequence effect on crack growth rate was also studied by alternating between axial and torsion cycles in a loading block. Mode I crack growth was observed. Torsion fatigue crack growth lives were shorter and crack growth rates were higher than for axial loading. This is explained by a larger plastic zone size produced by a compressive tangential stress acting parallel to the crack growth path. In block loading with dominated torsion cycles crack grown rate was slower in comparison with pure torsion, while in block loading with dominated axial cycles a faster crack growth rate occurred in comparison with pure axial loading. Effects of the stress state on the plane of crack growth and of one pair of cracks on a second pair are considered to explain these observations. Crack growth rates were correlated with stress intensity factor range with or without considering the T-stress effect. Short crack growth behavior near the threshold region is also discussed.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

Many engineering structures are subjected to various combinations of axial and torsion cyclic loading. In addition, many such components often contain a variety of notches such as holes, fillets and grooves. Therefore, the prediction of fatigue crack growth behavior from notches due to stress concentrations is of significance to a large number of engineering applications.

Mode I is typically found to control crack growth and fracture mode of different materials under tension and torsion cycling. However, mode I crack growth rate under cyclic torsion can be higher than that under uniaxial loading [1]. Brown and Miller [2] studied mode I fatigue crack growth under biaxial stress conditions for AISI 316 austenitic stainless steel. Thin rectangular plates with a through-thickness hole and two small opposite slots at the edge of the hole were subjected to mode I cyclic loading. They found that mode I crack growth accelerated by a negative T-stress and the magnitude of this effect depended on the T-stress amplitude. They proposed an equation to correlate experimental crack growth rate data based on the Dugdale model [3] and the Paris equation considering the size of plastic zone adjustment at the crack tip.

Smith and Pascoe [4] found similar results to Brown and Miller observations. Flat cruciform-shaped specimens made from HY100 high yield-strength steel were used with a thinned-down center section and subjected to biaxial tension–compression loading. They concluded that cyclic loads transverse to a normal or mode I crack affects crack growth rate due to changes in crack tip plasticity, where a tensile stress decreased crack rate and a compressive stress has the opposite effect. Also, mode II crack growth rates were found to be much greater than for the equivalent mode I crack.

Similar observations were made by Shanyavskiy [5] for thin sheet aluminum-based alloys with a central hole of 2 mm in diameter subjected to biaxial loading. Compressive stress applied parallel to the crack-growth plane caused a rotation effect resulting in the formation of spherical or ellipsoidal particles and faster growth rate. These particles are rolled between the opposite fracture-surfaces whose relative displacement is controlled by the K_{III} component. The concluded that for constant amplitude cyclic loads, including out-of-phase biaxial loads, crack growth rate during the mode I crack opening stage may be successfully simulated by equivalent stress intensity factor as a function of biaxial stress ratio and phase angle.

Thomson and Sheppard [6] performed a series of experimental studies on aluminum alloy 2024-T351 under uniaxial and torsion cyclic loading for smooth and fillet notched cylindrical solid specimens. They found torsional loading cases to result in higher slope in Paris equation due to higher crack growth rate in comparison with uniaxial loading. They discuss inapplicability of the LEFM

---

* Corresponding author. Tel./fax: +1 419 530 8213.
E-mail address: afatemi@eng.utoledo.edu (A. Fatemi).

0167-8442/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tafmec.2013.12.001

Nomenclature

$2a$	crack length including the hole diameter
A	crack growth rate equation coefficient
da/dN	crack-growth rate
da/dN_1	biaxial crack-growth rate
F_0	energy release correction function
n	crack growth rate equation exponent
$N_{0.2}$	fatigue life to 0.2 mm crack length
$N_{0.5}$	fatigue life to 0.5 mm crack length
$N_{0.5\div5}$	fatigue life from 0.5 mm to 5 mm crack length
Λ	biaxial stress ratio
σ_1	maximum principal stress
σ_a	axial stress amplitude
σ_u	ultimate tensile stress
σ_{xx}	stress parallel to crack surface
σ_{yy}	stress normal to crack surface
τ_a	shear stress amplitude
ΔK_I	mode I stress intensity factor range
ΔK_{th}	threshold stress intensity factor range

assumption for torsional loading due to the presence of a biaxial stress state and that applying the *J*-integral may be able to account for the effect of biaxial loads on the crack tip plastic zone size.

Tanaka et al. [7] carried out fatigue crack growth tests using thin-walled tubular specimens with a circular hole made of low-carbon steel. The loading included cyclic uniaxial tension–compression, and cyclic torsion with or without superposed static tension or with cyclic axial loading. In all cases cracks grew in mode I. They found crack growth rates for torsion and combined torsion with axial loading to be higher, as compared to uniaxial loading. They attributed the acceleration of crack growth to larger plasticity at the crack tip. The highest crack growth rate was observed to be for the case of cyclic torsion with static tension loading. The *J*-integral range determined from the relation between load and displacement was shown to be an appropriate parameter for crack growth analysis in the presence of significant plasticity.

Endo et al. [8–10] studied crack growth behavior of 0.37% carbon steel and a chrome-molybdenum steel under in-phase and out-of-phase axial-torsion loading. Smooth solid round specimens with a small drilled hole introduced into the surface were used. The diameter of the hole was either 100 or 500 μm and was equal to the hole depth. No significant effect of loading phase was found on long crack growth rates. However, short crack behavior was more sensitive to non-proportionality of the loading. This was attributed to the abrasion of crack surfaces which reduces the level of crack closure and, thereby, increases the net driving force under out-of-phase loading. To consider the effect of biaxial loading, they defined a net crack driving force parameter for fatigue crack propagation by modifying the expression for effective stress intensity factor range ΔK_{eff}. The effect of biaxial loading in this parameter is reflected in the values of amplitudes ratio of applied stress normal to the crack and applied stress parallel to the crack. This parameter was found to correlate in-phase and out-of-phase short crack growth rate data.

Nalla et al. [11] studied mixed-mode (mode I + II) fatigue crack growth thresholds for large and short through-thickness cracks in a Ti–6Al–4V turbine engine alloy. They observed fatigue thresholds for through-thickness cracks which were large compared to microstructural dimensions to be strongly influenced by mode-mixity. They concluded that although for large cracks fatigue cracking under mixed-mode loading is predominately a mode I phenomenon, mode-mixity influences thresholds by crack tip shielding resulting from crack-surface interference.

Carpinteri et al. [12] examined the behavior of a part-through-cracked notched shell with different notch configurations using 3D FEA and concluded the effect of the stress concentrator on the value of stress intensity factor to be significant. Mikheevskiy and Glinka [13] used a fatigue crack growth model based on crack tip region elastic–plastic stress/strain analysis where load-interaction effects in a load spectrum was simulated by accounting for residual compressive stresses produced by the reverse plastic deformation. They applied their model to crack growth rate analysis of specimens with a central through crack made of Al 7075-T6 alloy and showed good correspondence between experimental and predicted results.

Susmel and Taylor [14] used sharply notched low carbon steel specimens under in-phase mode I and II loading to study non-propagating crack behavior. They observed the early stage of crack growth to be mixed-mode, whereas the subsequent growth was mainly mode I dominated. They also observed the non-propagating crack length tended to increase as the mode II contribution to fatigue damage increased.

Makizaki et al. [15] investigated the effect of occasional mode II loading on subsequent mode I fatigue crack growth behavior by using thin-walled tubes made of 7075-T651 aluminum alloy. They found the occasional mode II loading has two contradictory effects on crack growth behavior, a retardation effect associated with the plastic deformation near crack tip, and an acceleration effect caused by mode II fatigue crack growth.

The overall goal of this study was to investigate fatigue crack growth behavior of notched specimens made of a common carbon structural steel subjected to axial and torsional loads. In addition, loading sequence effect on crack growth rate was studied by alternating between axial and torsion cycles in a loading block. In this paper, first the experimental program is described. Then, experimental results and observations are presented. This is followed by crack growth rate correlations for different loading conditions. Finally, conclusions based of the experimental observations and crack growth rate analyses are presented.

2. Experimental program

The material used in the present study was a low-carbon steel used for piping in nuclear power plants. The chemical composition of the material by weight is 0.24% C, 0.25% Si, 0.45% Mn, 0.2% Cr, and the balance Fe. The microstructure of the material was composed of ferrite and pearlite structure with ferrite grain size of about 20 μm. The yield strength is 365 MPa, the ultimate strength is 506 MPa, elastic modulus is 185 GPa, and the cyclic yield stress is 311 MPa.

Tubular specimens with a through thickness circular hole at the middle of gauge section were used. The gauge section of the specimen had an outer diameter of 24.2 mm, an inner diameter of 22 mm, and a wall thickness of 1.1 mm. The hole diameter was 3.4 mm and the hole geometry resulted in stress concentration factors of 3.29 and 3.98 for axial and torsion loadings, respectively [16].

Download English Version:

https://daneshyari.com/en/article/808734

Download Persian Version:

https://daneshyari.com/article/808734

Daneshyari.com