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Crack shape evolution under bending-induced partial closure

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ABSTRACT

In this paper, crack shape evolution under out-of-plane pure bending loads in plates with an initial through-thickness edge crack is investigated experimentally and computationally. Such cracks were numerically simulated by a step-by-step 3D finite element technique as an attempt to reproduce the evolving geometry of the crack front for the present problem, considering contact on the closed part of the crack faces. The purpose of this numerical analysis was to identify the particular issues of this type of simulation and to demonstrate that it is feasible. In the experiments, beach marks were generated to identify crack front shapes during crack growth. New fitting crack front curves are proposed using straight lines combined with quarter-ellipses with non-concentric centers.

1. Introduction

Fatigue crack growth (FCG) is an important failure mechanism in structures subjected to cyclic loading. Depending on the load type, an initial crack may change its shape during its FCG process. In particular, through-thickness cracks subjected to cyclic out-of-plane bending substantially change their shapes, because they do not tend to grow in those parts that are closed by the bending loads. However, due to this problem complexity, there are no analytical solutions for the evolving crack shape geometry during the growth process. In addition, relatively few studies addressed this problem in the literature.

In the case of a through-thickness edge crack in a plate under out-of-plane pure bending cyclic loading, as shown in Fig. 1, the distribution of normal stress varies along the crack front. Fig. 1(a) schematically depicts the out-of-plane pure bending test performed in this work. Fig. 1(b) shows an image of one of the tensile experiments to create the through-thickness pre-cracks. In the compression region, crack faces suffer contact and there is no crack propagation. In the tension region, the crack grows in Mode I and, therefore, the fatigue crack remains in the same plane of the original defect. In addition, the SIF varies along the crack front and, consequently, the front geometry becomes a part-through crack within the plane of the pre-crack. The challenge is to predict the non-trivial crack front shapes as it grows.

In relation to numerical studies of cracked plates under out-of-plane pure bending loading, Jones and Swelow [1] investigated the influence of crack closure and elasto-plastic behavior using assumptions of Kirchhoff plate theory by means of finite element analysis. Alwar and Nambissan [2] and Zhao et al. [3] performed a three-dimensional finite element analyses taking into account the closure of crack faces on the compression side and evaluated the stress intensity factor distribution along the crack front. Alwar and Thiagarajan [4] investigated the same problem considered large deformation. These studies

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Nomenclature

c	crack length at the plate bottom surface
$\mathbf{a}^*$	through-thickness notch size
W	plate width
t	plate thickness
ΔK_I	mode I stress intensity factor range
R	stress ratio
ΔP	range of applied load
$\Delta\sigma$	stress range
N	number of cycles
a, ***b***	depth and length of corner cracks, respectively semi-major axes of the quarter-elliptical curves
S_r	mean squared errors
O	center of the quarter-elliptical curves
d	distance between the center ***O*** and the plate left face
E	Young's modulus
ν	Poisson's ratio
l_a	element size along the crack front
l_e	ring size (a distance perpendicular to the crack front)
Δa_i	crack increment length at point i
ΔK_{th}	fatigue threshold
α, m	materials constants
ΔN	intervals of number of cycles in each crack growth step
Δa_{max}	maximum crack growth increment
ΔK_{max}	maximum value of stress intensity factor
ΔK_i	mode I stress intensity factor in each point i

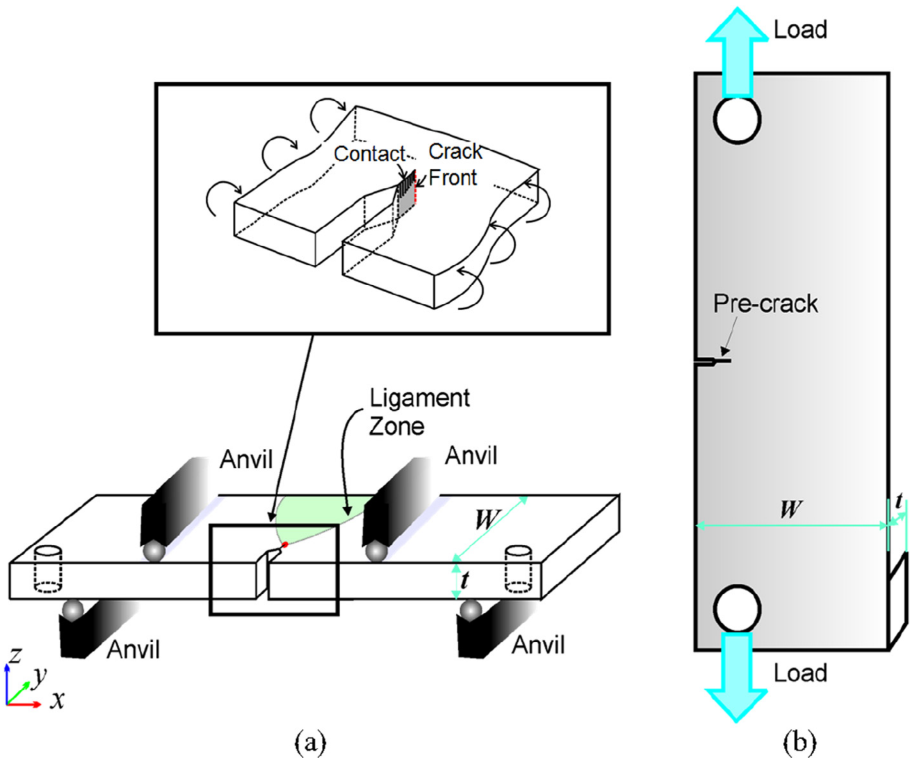

Fig. 1. Statement of the problem: (a) out-of-plane pure bending loads and (b) pre-crack under fatigue tension loads.