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Study of anisotropic crack growth behavior for aluminum alloy 7050-T7451

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ABSTRACT

Hill's normalized plastic zone at crack tip under mode-I and mixed-mode loadings were studied in compact-tension-shear specimen. Effects of the parameters of Hill's criterion on the normalized plastic zone were analyzed. Moreover, the shapes of normalized plastic zones for distortional and total strain-energy-density were investigated. To analyze the crack growth behavior by different normalized plastic zones, fatigue crack growth tests of AA7050-T7451 were performed using digital image correlation technique. The initiation angle predicted by anisotropic *R*-criterion under mixed-mode loading is closest to experimental data.

1. Introduction

Plastic anisotropy is an inevitable phenomenon due to some material processing techniques, such as rolling and extruding processes. Effect of plastic anisotropy on crack growth behavior under complex loading in the domain of fracture mechanics is significant. Furthermore, investigations of crack initiation and propagation considering the effect of plastic anisotropy are meaningful to predict cracks of aircraft structure parts in the damage tolerance and the design of full-life.

Gdoutos and Meletis [1] used strain-energy-density (SED) theory to analyze the fracture behavior of anisotropic plate and revealed the dependence of crack growth angle and crack direction on material properties. Theocaris and Philippidis [2] applied *T*-criterion to predict the mixed-mode fracture characteristics of anisotropic plates, and the predictions for dimensionless fracture stress of a plate with an inclined crack fit with experimental data. Khan and Khraisheh [3] employed the Hill's criterion to obtain normalized variable-radius crack tip plastic zone, and the study shows a significant effect of plastic anisotropy on the normalized plastic zone and the crack initiation angle. Tvergaard and Legarth [4] applied an elastic-viscoplastic material model to account for plastic anisotropy on mixed-mode interface crack growth and concluding that the resistance to crack growth is sensitive to anisotropy. Makas [5] studied the influence of rolling-induced anisotropy on fatigue crack initiation and short crack propagation for AA2024-T351 and finding that fractured particles for longitudinal cruciform samples are responsible for crack nucleation while nucleated cracks in transverse samples are caused by deboned and fractured particles. Jin et al. [6] carried out four-point bend fatigue tests on L-T (Rolling-Transverse), L-S (Rolling-thickness), and T-S planes of AA7075-T651 respectively to study effects of preceding fractured particles and drawing that the anisotropy of fatigue strength results from the difference in grain structure and the particle between on these planes. Atzori et al. [7] studied fatigue behavior of several notched carbon steels under multi-axial loading by using SED theory, and the energy-based approach makes all the fatigue data obtained from the notched specimens to be concentrated in a single scatter band. Tavares et al. [8] reported the comparison of the strain field of numerical modeling against experimental data from digital image correlation (DIC) method under Mode-II loading of fatigue test, and the obtained results are an important step towards a

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Nomenclature

a	crack length
a_{11}, a_{12}, a_{22}	coefficients of function for normalized plastic zone radius
B	thickness of the compact-tension-shear specimen
C	material constant of Paris Equation
$f_{K_i}(\psi)$	function of loading angle ψ
E	elastic modulus
K_i	stress-intensity-factors of mode-I or mode-I
m	material constant of Paris Equation
N_u	number of fatigue cycles
P	applied load
Q	material coefficient of Voce Equation
r_{d}	radius of plastic zone for distortional strain-energy-density (SED)
$\bar{r}_{\mathrm{d}}$	radius of normalized plastic zone for distortional SED
r_s	radius of plastic zone for total SED
$\bar{r}_s$	radius of normalized plastic zone for total SED
R_{M}	radius of Mises's plastic zone
$\overline{R}_M$	radius of Mises's normalized plastic zone
R_{M}	radius of Hill's plastic zone
$\overline{R}_{\mathrm{H}}$	radius of Hill's normalized plastic zone
r_0,r_{45},r_{90},r_θ	plastic strain ratio at 0°, 45°, 90°, and θ directions for rolling direction
W	width of the CTS specimen
α	linear weight factor between Swift and Voce Equations
β	material coefficient of Voce Equation
θ	polar angle at the crack tip
κ	material constant depending upon stress states
ν	Poisson's ratio
σ_{sa}	saturated stress of Voce Equation
σ_{app}	applied stress around crack tip
$\bar{\sigma}_M$, $\bar{\sigma}_H$	Mises equivalent stress and Hill equivalent stress
σ_x, σ_y, τ_{xy}	normal and shear stress components
$d\varepsilon_x$, $d\varepsilon_y$	strain increment along x and y directions
$d\gamma_{xy}$	shear strain increment on the xy plane
ε_p	plastic strain
ε_0	prestrain of Swift Equation
ψ	loading angle
F, G, H, N	parameters of Hill's criterion

development of a practical tool for crack behavior prediction in fatigue dominated events.

The experimental data shown in Refs. [9,10] were not fitted well with the yield surfaces of the Von Mises type including Hill's criterion of anisotropy. To describe anisotropic yielding behavior preferably, Barlat et al. [11–13] proposed and developed specific yield surfaces for aluminum sheets. Moreover, Bron and Besson [14] extended the yield functions given by Barlat et al. [11] and Karafillis and Boyce [15] to represent plastic anisotropy of aluminum sheets. Although Hill's criterion may have some limitations to describe yield surface of 7050-T7451 aluminum alloy, the purpose is to focus on providing a heuristic thinking for anisotropic crack growth behavior.

Efforts were made to reveal the law of crack growth behavior of aluminum alloy 7050-T7451 [16–19]. However, rare reports considered the effect of plastic anisotropy on crack growth behavior. Since the anisotropic *R*-criterion [3] was rarely applied to predict crack initiation angle of compact-tension-shear (CTS) specimens, Hill's normalized plastic zones under mixed-mode loading in CTS specimens were investigated to analyze fatigue crack growth behavior. To comprehensively analyze the crack growth behavior the normalized plastic zone for energy density was investigated. Crack initiation angle predicted by three criteria, i.e. anisotropic *R*-criterion, the minimum strain energy density criterion (*S*-criterion), and maximum tangential stress criterion (MTS-criterion) were compared with experimental data under mode-I and mixed-mode loadings in CTS specimen. Crack growth rate was investigated to analyze the relation between crack growth behavior and normalized plastic zones under mode-I and mixed-mode loadings of CTS specimen as well. Then, the crack initiation mechanism under mode-I and mixed-mode loadings was discussed based on the analyses of fracture appearance.

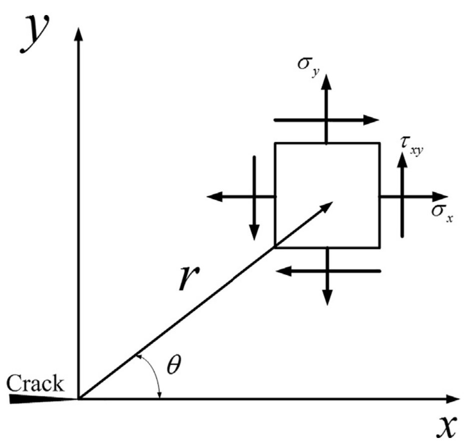

Fig. 1. Stress field at crack tip.