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Acceleration of fatigue crack growth due to occasional mode II loading in 7075 aluminum alloy

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ABSTRACT

The effect of an occasional mode II loading on the subsequent mode I fatigue crack growth was investigated in a thin-walled 7075-T6511 aluminum alloy tube. Careful observation of crack growth behavior revealed that an occasional mode II loading has two contrasting effects on the subsequent crack growth. First is a retardation effect that is associated with a crack closure development due to the mode II loading. However, this effect was insignificant with respect to the crack growth life as a whole. Second is an acceleration effect that is associated with an accelerated crack growth rate in mode II. It was found that, in a relatively high ΔK regime, mode II crack growth was from one to two orders of magnitude faster than mode I crack growth. This study shows that mode II crack growth should be considered as a predominant factor in evaluating the effect of an occasional mode II loading for a mode I crack in 7075 aluminum alloy.

1. Introduction

In practical service conditions for various machine components and structures in aircrafts, automobiles and power generators, etc., shear loadings are occasionally mixed with cyclic tension–compression loadings (*e.g.* bending and twisting of an aircraft wing). Thus, the effect of occasional mode II loading upon mode I fatigue crack growth has been a matter of concern for various materials [1–7].

With respect to the underlying issues, Nayeb-Hashemi and Taslim [1] studied the effect of a single mode II cycle on subsequent mode I growth in a quenched and tempered AISI 4340 steel. They reported that the mode II loading causes crack growth acceleration for a very short distance, much smaller than the transient plastic zone size. Further, Decreuse et al. [2] obtained similar results for S355NL steel. Sander and Richard [3] carried out a series of fatigue tests to investigate the effect of mixed mode overloading in 7075-T651 aluminum alloy. They found that a pure mode II overloading had a negligible influence on the subsequent mode I growth. In contrast, Dahlin and Olsson [4–6] demonstrated a marked reduction of subsequent mode I growth due to a single mode II loading in AISI 01 steel. Retardation of crack growth was also observed by Hua and Fernando [7] in a quenched and tempered low alloy steel.

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Nomenclature

a	half crack length
$CTOD_{max}$	maximum crack tip opening displacement
$CTOD_{min}$	minimum crack tip opening displacement
da/dN	crack growth rate
K_I, K_{II}	stress intensity factors in modes I and II
K_{max}	maximum stress intensity factor
K_{min}	minimum stress intensity factor
N	number of cycles
R	stress ratio ($=K_{min}/K_{max}$)
R_I, R_{II}	stress ratio in modes I and II
$\Delta CTOD$	range of crack tip opening displacement
ΔK	stress intensity factor range
ΔK_I, ΔK_{II}	stress intensity factor ranges in modes I and II
$\Delta K_{II\ single}$	stress intensity factor range in mode II for a single shear loading
r_{pII}	size of forward plastic zone in mode II
σ_a	normal stress amplitude
σ_{YS}	yield stress
τ_a	shear stress amplitude

Acceleration or retardation due to occasional mode II loading, if any, has been attributed to the following crack closure mechanisms [1,5]: (i) roughness induced fatigue crack closure (RIFCC) caused by a mismatch between crack faces due to relative tangential displacement, and (ii) plasticity-induced fatigue crack closure (PIFCC) caused by a large stretch of material in the vicinity of the crack tip. In the literature, Dahlin and Olsson [5] analyzed the RIFCC caused by a single mode II loading by using a theoretical model by Budiansky and Hutchinson [8]. They successfully simulated the experimental results for AISI 01 steel and showed that the recovery distance (*i.e.* the amount of crack growth required for the crack growth rate to revert to its original level) is much larger than the size of the mode II induced plastic zone. On the other hand, Nayeb-Hashemi and Taslim [1] discussed the PIFCC due to mode II overloading. It is well known that mode II loading can produce a much larger plastic zone compared to mode I loading. Correspondingly, Fig. 1 illustrates the shapes and dimensions of the respective plastic zones formed by modes I and II loadings based on the von Mises yield condition [9]. Nayeb-Hashemi and Taslim [1] point out that mode II overloading can cause a small amount of crack acceleration while mode I overloading causes a significant retardation, both of which are closely related to the amount of plastic stretch near the crack tip as well as the crack face interference. From these studies [1,4–6], we can infer that RIFCC can play more dominant role than PIFCC in determining the behavior of subsequent mode I growth after occasional mode II loading. Nonetheless, it is not a straightforward task to justify whether occasional mode II loading causes acceleration or retardation for the subsequent crack growth for other loading conditions and materials. To understand such a complicated phenomenon, the effects of these factors need to be quantified based on experimental observations and adequate mechanistic modeling.

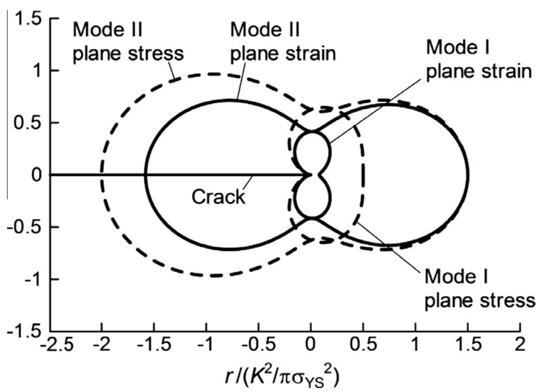

Fig. 1. Shapes and dimensions of the plastic zone formed by the modes I and II loadings.