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Fatigue crack growth predictions based on damage accumulation ahead of the crack tip calculated by strip-yield procedures
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Abstract
Elber assumed a long time ago that $\Delta K_{eff}$ is the driving force for fatigue crack growth (FCG), and his hypothesis is the basis for strip-yield models widely used to predict residual lives of cracked components. However, this hypothesis cannot explain many load sequence effects observed in practice. Hence, it is at least worth to verify if FCG models based on $\Delta K_{eff}$ are indeed intrinsically better than concurrent models based on other principles. To do so, the same mechanics is used to predict FCG rates based both on Elber’s ideas and on the alternative view that FCG is instead due to damage accumulation caused by the cyclic strain history ahead of the crack tip, an idea does not need or use the $\Delta K_{eff}$ hypothesis. To compare both approaches fairly, FCG rates are estimated by damage accumulation using the cyclic strain ranges induced by plastic displacements calculated by the very same procedures used by strip-yield models, assuming there are strain limits associated both with FCG thresholds and with material toughness. Despite based on apparently conflicting principles, both models can reproduce quite well FCG curves, a somewhat surprising result. Besides confirming that data fitting cannot be used to prove any model superiority, this result indicates that the $\Delta K_{eff}$ hypothesis is not a necessary requirement to explain the FCG behavior.

Keywords: Fatigue crack growth models; strip-yield mechanics; fatigue crack closure; effective stress intensity range; damage accumulation ahead of the crack tip.

Introduction
Fatigue life predictions of cracked structural components are required in most design and/or structural integrity evaluation tasks. Since Paris and Erdogan clearly demonstrated that stable fatigue crack growth (FCG) rates $da/dN$ correlate well with stress intensity factor (SIF) ranges $\Delta K$ [1], many similar rules have been proposed to consider effects of other parameters that can affect FCG rates as well, such as the peak load $K_{max}$ or the load ratio $R = K_{min}/K_{max}$, as well as the material limits for $da/dN$, namely FCG thresholds $\Delta K_{th}(R)$ and the critical SIF $K_{IC}$ or $K_C$ [2]. Another important issue for FCG modeling came after Elber experimentally found the crack closure phenomenon [3]. He observed that fatigue cracks can partially close over the lower portion of their load cycles even under $R > 0$, and only completely open after the applied SIF exceeded the so-called crack opening load $K_{op}$. Moreover, from this observation, he then assumed that FCG can only occur only after the crack tip is fully open under loads greater than $K_{op}$ (supposing that only then they would become able to expose their tips to additional fatigue damage) [4]. Consequently, he postulated that $\Delta K_{eff}$ ($\Delta K_{eff} = K_{max} - K_{op}$ if $K_{op} > K_{min}$, or $\Delta K_{eff} = \Delta K$ otherwise) would be the actual FCG driving force (instead of SIF ranges $\Delta K$ or SIF combinations like $\{\Delta K, K_{max}\}$ or $\{\Delta K, R\}$).

Since the $\Delta K_{eff}$ hypothesis can reasonably explain many (but certainly not all) sequence or load-order effects in FCG, like crack growth delays or arrests after overloads (OL) and the $R$-sensitivity of FCG thresholds (on non-inert environments), it has been popular among fatigue experts ever since its proposal. It has been used as the basis for many semi-empirical FCG models, in particular the so-called strip-yield models (SYM) that numerically estimate $K_{op}$ and $\Delta K_{eff}$, and from them FCG lives using a suitable $da/dN = f(\Delta K_{eff})$ equation properly fitted to experimental data [5–9]. However, although the fatigue crack closure phenomenon is well documented and proven [10–13], its real significance for FCG is still controversial, to say the least. Indeed, the $\Delta K_{eff}$ hypothesis cannot explain many FCG peculiarities, see for instance [14–19] for an overview of them.
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