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A model for the determination of the fatigue life in technical alloys containing large and small defects

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Abstract

The determination of the fatigue life in technical alloys containing large and small defects must rely on a propagation model which accounts for short and long crack growth. Recently an analytical model which incorporates propagation in the short crack regime and plastic correction for the crack driving force has been presented by two of the authors.
This work is intended to show further validation of the model, taking into account data sets for different materials with different testing conditions.
Despite the assumptions about missing parameters, the value of which had to be taken from the literature, the predictions showed a fairly good approximation of the fatigue lives. A possible interpretation of the results in terms of multiple crack initiation and propagation at higher loads is proposed.

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Keywords: Fatigue strength; Crack propagation; Short cracks.

1. Introduction

The overall lifetime of a cyclically loaded structure can be subdivided into three stages: i) crack initiation; ii) small and long fatigue crack propagation; iii) final fracture. In the small crack growth stage both micro-structurally

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Nomenclature

a	crack length
a_i	initial crack length
f	plastic correction function
k	exponent in the McEvily's law
m	exponent in the Paris' law
C	constant in the Paris' law
E	modulus of elasticity
R	stress ratio
R_m	ultimate tensile strength
U	crack closure function
U_{LC}	value of the crack closure for long cracks
ϕ	boundary correction function
σ_f	flow stress
$\sigma_{\max}$	maximum applied stress
σ_Y	yield strength
ΔK	stress intensity factor range
ΔK_{eff}	effective stress intensity factor range
ΔK_{pl}	plasticity-corrected stress intensity factor range
ΔK_{th}	threshold stress intensity factor range
$\Delta K_{th,eff}$	effective threshold stress intensity factor range
ΔL_r	cyclic ligament yielding parameter
$\Delta\varepsilon_{ref}$	reference strain range
$\Delta\sigma_{ref}$	reference stress range

and mechanically small cracks must be considered, see Polak (2003). Micro-structurally small means a crack size in the order of micro-structural features (such as the grain size), whereas mechanically small refers to the order of mechanical quantities, such as the plastic zone size or a notch stress field.

In the case of engineering materials with large second phase particles the initiation stage is rather small and the overall lifetime is usually controlled by the extension of small cracks which are, if the initial defects are large enough, mechanically small cracks.

In Zerbst et al. (2011) two of the present authors proposed a model for fracture mechanics based determination of the fatigue strength and life, based on the assumption of a negligible short crack initiation stage which allowed them to base the analysis on a pre-existing defect treated as initial crack. The model is briefly presented in this paper and further validation is provided using literature data. Some limitations emerged and a possible extension of the propagation model is proposed based on experimental evidences in order to improve the predictions.

2. Description of the proposed model

The crack propagation model is based on a modification of the Paris' equation in order to take into account the following effects:

- Calculation of the crack growth rates in the short and long crack regime
- Plastic correction to the crack driving force
- Plasticity-induced crack closure

The resulting crack growth rates are calculated as