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A model for fracture mechanics based prediction of the fatigue strength: Further validation and limitations

U. Zerbst [a,*], M. Madia [a], H.Th. Beier [b]

[a] BAM-Federal Institute for Materials Research and Testing, 9.1, D-12205 Berlin, Germany
[b] Technische Universität Darmstadt, IFSW, D-64287 Darmstadt, Germany

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ABSTRACT

Recently two of the authors of the present paper proposed a model for a fracture mechanics based prediction of the *S–N* characteristics of metallic components with large microstructural defects and supported this by a validation exercise on tensile plates made of an aluminium alloy AL5380 H321. Here the authors extend the study using a number of further data sets from the literature for which data were available at different *R* ratios. These data include two aluminium alloys, Al 2024-T3 and Al 7075-T6, and a ductile cast iron, EN-GJS-400-18-LT. Despite of necessary assumptions for the compensation of partially missing input information the results were fairly reasonable with the exception of one data set. The authors identify high applied stress levels in combination with potential multiple crack initiation as the probable root of the problem and propose a scheme how the model can be extended for taking into account crack initiation.

1. Introduction

The lifetime of a cyclically loaded structure can be subdivided into three stages: (i) crack initiation; (ii) small and long fatigue crack propagation; and (iii) final fracture. The small crack growth stage can be further subdivided by considering micro-structurally and mechanically small cracks [1]. Micro-structurally small means a crack size in the order of microstructural features such as the grain size whereas mechanically small refers to the order of mechanical discontinuities 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 [2] 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 which they treated as initial crack. The model is briefly introduced in Section 2 of this paper. In Section 3 the authors provide further validation using literature data which also revealed some limitation of the model, which is finally discussed in Section 4.

2. The model

The scheme of the proposed model is shown in Fig. 1. It is characterized by the following steps:

* Corresponding author.
E-mail address: uwe.zerbst@bam.de (U. Zerbst).

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Nomenclature

a	crack length/for surface cracks: crack depth
a_i	initial crack depth (in the model depth of a pre-existing defect)
a_0	fit parameter in Eq. (13)
B	specimen thickness
c	half crack length at surface (semi-elliptical crack)
c_i	initial half crack length at surface
da/dN	fatigue crack propagation rate
E	modulus of elasticity
E'	E for plane strain conditions (Eq. (1))
f	crack closure function (Eq. (6))
F	tensile force
F_Y	limit load (Eq. (3))
k	exponent of the ΔK_{th}-a function (Eq. (13))
K	stress intensity factor (K factor)
K_{max}	maximum K factor in a loading cycle
K_{op}	K factor above which the crack is open
K_t	stress concentration factor
K_0	K factor referring to σ_0
L_r	ligament yielding parameter ($=F/F_Y = \sigma_{ref}/\sigma_Y$)
N	number of loading cycles
N_i	number of loading cycles to crack initiation
R	R ratio ($=\sigma_{min}/\sigma_{max}$ or K_{min}/K_{max})
U	crack closure function ($=\Delta K_{eff}/\Delta K$)
U_1, U_2	crack closure function for the (mechanically) small and the long crack
W	specimen width
Y	shape function of the stress intensity factor
α, α_g	local and global constraint parameter (Eq. (12))
ΔF	tensile load range ($=F_{max}-F_{min}$)
ΔJ	cyclic J integral (Eq. (2))
ΔK^J	cyclic K factor ($=K_{max}-K_{min}$)
ΔK_{eff}	crack closure effect corrected ΔK ($K_{max}-K_{op}$)
ΔK^J	plasticity corrected ΔK
ΔK_{th}	fatigue propagation threshold
ΔK^J_{eff}	plasticity corrected ΔK_{eff} (Eq. (1))
$\Delta K_{th,eff}$	intrinsic fatigue propagation threshold
$\Delta K_{th,lc}$	fatigue propagation threshold, long crack regime
$\Delta K_{th,op}$	crack closure effect induced component of ΔK_{th}
ΔL_r	cyclic ligament plasticity parameter (Eq. (3))
$\Delta\sigma_{ref}$	cyclic net section reference stress (Eq. (3))
ν	Poissons ratio
σ	stress, general
σ_{max}	maximum stress in a loading cycle
σ_{open}	stress above which the crack is open
σ_{yy}	crack opening stress
σ_Y	yield strength of the material
σ_0	reference stress in Eq. (11), in the present model the stabilized cyclic σ_Y
$\sqrt{area}$	crack area
$\sqrt{area}^*$	crack area at the transition from small to large crack (Fig. 2)
$\sqrt{area_i}$	crack area of the initial crack

(a) Introduction of an initial crack (in terms of crack depth a_i or Murakami's parameter $\sqrt{area_i}$), the size of which is defined by material defects (or statistical defect size distributions). The nature of these defects is strongly dependent on production processes and applications. Examples are non-metallic inclusions, pores and cavities, corrosion pits, welding defects or scratches onto the surface (cf. [3]). In any case it is expected that a very limited number of loading cycles is sufficient to transform the defect into a crack.