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Fatigue behaviour of defective cast iron

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Abstract

With the analysis example of a cast iron component a Finite Element Analysis (FEA) based modelling and post-processing methodology is proposed for the multiaxial high-cycle fatigue assessment of surface defects. Methods are proposed for the measurement and mechanical description of surface defects using an ellipsoid simplification and the well-known size parameter from Murakami (2002). Different methods are compared for the stress-computation near surface defects: elastic FEA, elastic-plastic FEA with nonlinear kinematic hardening material model, and analytical calculations with the Equivalent Inclusion Method from Eshelby (1957). The Defect Stress Gradient (DSG) approach from Vincent et al. (2014) is applied to predict crack initiation, whereby a new method is proposed for the estimation of the stress gradient, which allows the presentation of the DSG utilisation factor results field.

Keywords: multiaxial fatigue; crack initiation; FEA; stress gradient; surface defects; nodular cast iron

1. Introduction

Surface defects play a major role in the cast material fatigue, since they are the most likely cause of crack initiation leading to fracture in the high cycle fatigue regime. The fatigue design of industrial cast components is therefore

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Nomenclature

a_{∇}	material parameter describing the type of defect and its influence in the Defect Stress Gradient (DSG) approach (μm)
k_{DSG}	utilization factor computed with the DSG approach predicting crack initiation at 1 (-)
$A_{\%}$	elongation at fracture (%)
$A;B;C$	major-, minor axis and depth of an (approximately) ellipsoid shaped surface defect (mm)
C_i	constant proportional to the initial hardening modulus in the nonlinear kinematic hardening model (MPa)
E	Young's modulus (GPa)
HV	Vicker's hardness (kgf/mm^2)
$J_{2,a}$	amplitude of the second invariant of the deviatoric stress tensor over a load cycle (MPa)
R	load ratio, describing the type of the cyclic loading (-)
R_m	tensile strength (MPa)
$R_{p0.2\%}$	yield strength under monotonic loading (MPa)
$R_{p0.2\%cy}$	yield strength under cyclic loading (MPa)
$\sqrt{area}$	defect size parameter from Murakami (2002) (μm)
$\sqrt{area}_{\max}$	modified version of the defect size parameter from Murakami (2002) (μm)
α_{Cr}	material parameter in the Crossland equivalent stress (-)
β_{Cr}	material parameter in the Crossland criterion (MPa)
γ_i	nonlinear recall parameter in the nonlinear kinematic hardening model (-)
σ_{Cr}	Crossland equivalent stress (MPa)
$\sigma_{Cr.\max}$	maximum value of the Crossland equivalent stress on the defect surface (MPa)
$\sigma_{Cr,\max}^{FEA-elas.}$	$\sigma_{Cr.\max}$ computed with linear elastic FEA (MPa)
$\sigma_{Cr,\max}^{FEA-ep.}$	$\sigma_{Cr.\max}$ computed with elastic-plastic FEA (MPa)
$\sigma_{Cr,\max}^{EIM}$	$\sigma_{Cr.\max}$ computed with the Equivalent Inclusion Method from Eshelby (EIM) (MPa)
$\sigma_{Cr.0}$	value of the Crossland equivalent stress at the defect centre on the surface, without the defect (MPa)
$\sigma_{D,R-1}^{ten}$	fatigue limit under fully reversed tension-compression (R-1) loading (MPa)
$\sigma_{D,R0.1}^{ten}$	fatigue limit under pulsating tensile (R0.1) loading (MPa)
$\sigma_{D,R-1}^{tor}$	fatigue limit under fully reversed torsion loading (MPa)
$\sigma_{h,\max}$	maximum of the hydrostatic stress over a load cycle (MPa)
σ_y	yield stress in the nonlinear kinematic hardening model (MPa)

inseparable from the casting process and the quality inspections. The quantification of the effect of different surface defects is a necessity in the component design, casting process planning and during quality inspections. From a theoretical standpoint the methods for fatigue assessment of defective material either model the defect as a notch within the framework of continuum mechanics, or as a crack leading to fracture mechanical description of the problem. For the high-cycle fatigue design of components with complex geometry under multiaxial loading conditions the following methods are the most prevalent:

- approaches based on the Linear Elastic Fracture Mechanics, modelling defects as cracks,
- the enhanced version of the empirical Murakami approach from Yanase and Endo (2014), which builds on the correlation between the fatigue limit and the Vickers hardness, and the size parameter $\sqrt{area}$ and $K_{I.\max}$,
- the Critical Distance Method from Susmel and Taylor (2003) applying multiaxial fatigue criteria combined with a correction of local stresses through the evaluation at a critical distance from the hot-spot,
- different non-local energy based fatigue criteria, such as (Saintier et al. 2013), using the concept of the volume influencing crack initiation,