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The IBESS model – Elements, realisation and validation

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ABSTRACT

The work presents the procedure developed within the German research project *IBESS*, which allows for the fracture mechanics-based prediction of the fatigue strength of welded joints under constant amplitude loading. Based on the experimental observations of the crucial failure mechanisms, the approach focuses on the short crack propagation, where elastic-plastic fracture mechanics and the build-up of closure effects must be considered, as well as the variability of the local geometry at the weld toe and the modelling of multiple crack interaction. Analytical solutions are provided for the approximation of the through-thickness stress profiles at the weld toe and for the determination of the crack driving force in the form of a plasticity-corrected stress intensity factor range ΔK_p. Proposals for the determination of the initial crack size and the crack closure factor are also included.

The approach is validated against a large number of experimental data, which comprises fatigue tests on individual cracks monitored by heat-tinting and beach-marking techniques, as well as stress life curves. Three kinds of welded joints, two steels of significant different strength, two welding techniques and three stress ratios are considered. The results show that the procedure provides good estimations of the statistical distribution of the fatigue strength of welded joints both for the finite and infinite life regime. Furthermore, the predictions are compared with available benchmark data for structural steels.

1. Introduction

The life-cycle management of a component has gained more and more attention in the last decades as a primary instrument for industries to reduce their operational and maintenance costs, beside reducing losses due to fatigue failures. In some cases, it has been reported that the underestimation of the lack of awareness in failure mechanisms of plants led to casualties due to the loss of technical integrity [1]. Other studies demonstrated that the life of some long-life components could be extended up to 50% without compromising safety [2]. To achieve this goal, a thorough understanding and modelling of the fatigue failure mechanisms is required.

In this sense, a contribution is given by the procedure presented in this paper, which shall provide a solid and reliable method for the fracture mechanics-based determination of the fatigue strength of welded joints under constant amplitude

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Nomenclature

a_i	initial crack depth
$a_{i,t}$	initial crack depth at the transition between short and long crack limit solutions
a_0	El Haddad parameter
a^*	additional parameter in the El Haddad model
b	exponent in the cyclic R-curve power law
$\|\|\boldsymbol{b}\|\|$	magnitude of the Burgers vector
f	crack closure function for long cracks
$f(\Delta L_r)$	plasticity correction function
f_0	limit function for the reference yield stress in case of combined loading
h	excess weld metal
k	depth of the secondary notch
k	slope of the S-N curve in double logarithmic scale (Figs. 28–35)
k_a	coefficient for the approximation of the crack aspect ratio
k_t	elastic stress concentration factor (SCF)
ℓ	width of the geometric partition of the weld toe
m	parameter in the crack propagation law
$m(\xi, a)$	general expression of the weight functions for the calculation of the stress intensity factors
n'	hardening exponent in the Ramberg-Osgood material law
p	parameter in the crack propagation law
p_i	coefficients in the stress concentration factor solution
q_i	coefficients in the through-thickness stress profile solution
A	coefficient in the cyclic R-curve power law
A_i	coefficients in the crack closure function f
A_{iA}	coefficients in the expressions of the weight function for the deepest point of the crack
B_{iA}	coefficients in the expressions of the weight function for the deepest point of the crack
C	parameter in the crack propagation law
C_i	coefficients of the stress polynomials
C_{iC}	coefficients in the expressions of the weight function for the surface point of the crack
D_{iC}	coefficients in the expressions of the weight function for the surface point of the crack
E	modulus of elasticity
E_l	parameter in the through-thickness stress profile solution
F_i	influence coefficients
F_{iC}	coefficients in the expressions of the weight function for the surface point
G_l	parameter in the through-thickness stress profile solution
K'	parameter in the Ramberg-Osgood material law
K_f	stress intensity factor at the flow stress
K_{LC}	stress intensity factor solution for long cracks
K_{min}	stress intensity factor at the minimum stress in the fatigue cycle
K_{max}	stress intensity factor at the maximum stress in the fatigue cycle
K_{plate}	stress intensity factor for a crack in a smooth plate in the definition of M_k
K_r	stress intensity factor resulting from the residual stresses
K_{SC}	stress intensity factor solution for short cracks
K_{weld}	stress intensity factor for a crack at weld toe in the definition of M_k
J_e	elastic J-integral
L	weld width
M_k	stress intensity magnification factor
M_{iA}, M_{iC}	coefficients in the expressions of the weight functions
P_i	coefficients in the expressions of the reference yield stress solutions
P_{ii}	coefficients in the expressions of the reference yield stress solutions
Q	shape factor of an ellipse used the weight function solutions
R	stress ratio ($=\sigma_{min}/\sigma_{max}$)
R_m	ultimate tensile strength
T	thickness of the base plate
T_l	parameter in the through-thickness stress profile solution
U	crack closure factor
U_{LC}	crack closure factor for long cracks
Y_{iA}	coefficients in the expressions of the weight function for the deepest point of the crack
α	weld flank angle
α_g	constraint factor

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