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Fracture-mechanics based prediction of the fatigue strength of weldments. Material aspects

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ABSTRACT

Any fracture mechanics based determination of the fatigue strength of weldments requires different input information such as the local weld geometry and material data of the areas the crack is passing through during its propagation. The latter is so far not a trivial task as the fatigue crack is usually initiated at the weld toe at the transition from the weld metal to the heat affected zone. Furthermore, the crack propagates through the different microstructures of the weldment even into the base metal and causes final fracture. This paper describes how the material input information has been gained particularly for heat affected zone material by thermo-mechanically simulated material specimens for two steels of quite different static strength. The data comprise the cyclic stress-strain curve, the crack closure effect-corrected crack growth characteristics, fatigue threshold values for long cracks, the dependency of the parameter on the crack length and monotonic fracture resistance. The substantial experimental effort was necessary for the validation exercises of the IBESS approach, however, within the scope of practical application more easily applicable estimating methods are required. For that purpose, the paper provides a number of appropriate proposals in line with its check against the reference data from the elaborate analyses.

1. Introduction

Since the main focuss of the present paper is on the determination and discussion of material input data for the application within the so-called IBESS method, some words are due about the latter, however, without going in detail. For more extensive discussions see the papers of the present special issue and particularly those of Zerbst et al. [2] for some basic understanding and Madia et al. [12] with respect to the IBESS methodolgy. The acronym IBESS stands for "Integral fracture mechanics based determination of the fatigue strength of welds". The method combines commonly used fracture mechanics approaches such as the NASGRO equation for long fatigue crack propagation with a number of innovative elements such as (a) a method for the analytical determination of a cyclic elastic-plastic crack driving force and (b) for the gradual build-up of

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Nomenclature

a	crack length
a_0	El Haddad parameter (Kitagawa-Takahashi diagram), Eqs. (22) and (23)
a_0	initial crack length, monotonic fracture resistance test, Eq. (24)
a^*	additional term for modified El Haddad's model in IBESS, Eqs. (22) and (23)
b, c	coefficients of the Manson-Coffin-Basquin approach
B	specimen thickness
C, n, p	fit parameters of the da/dN-ΔK curve, Eq. (10)
da/dN	fatigue crack propagation rate
E	modulus of elasticity
f	crack closure function, Eqs. (10) and (11)
h	excess weld metal
HB	Hardness according to Brinell
HV	Hardness according to Vickers
HV1	Vickers hardness estimated using a load test of 1 kp (ca. 9.8 N)
J	monotonic J integral
$J_{0.2}$, $J_{0.2,BL}$	resistance against stable crack extension (monotonic loading), Eq. (26) and (27)
J_c	monotonic fracture resistance (ductile-to-brittle transition range)
J_{max}, Δa_{max}	validity criteria for monotonic R curve testing, Eqs. (24) and (25)
k	slope of the finite life S-N curve, Eq. (1)
K	stress intensity factor
K_c^J	critical stress intensity factor formally derived from J_c, Eq. (26)
K_{mat}	resistance against monotonic fracture, general term
K_{max}	minimum K-factor in a loading cycle
K_{min}	shift parameter of the 3 parameter Weibull distribution (Master curve concept, Eq. (27))
K', n'	coefficients of the Ramberg-Osgood description of the cyclic stress-strain curve
K_0	stress intensity factor of the tension plate at a stress level of σ_0, Eq. (16)
K_0	scale parameter, 3-parameter-Weibull distribution (Master curve concept, Eq. (27))
K_{max}	maximum K-factor in a loading cycle
K_{min}	shift parameter, 3-parameter-Weibull distribution (Master curve concept, Eq. (27))
ℓ	section width along the weld toe (IBESS approach)
m	shape parameter, 3-parameter-Weibull distribution (Master curve concept, Eq. (27))
N	number of loading cycles
R	R ratio (= $\sigma_{min}/\sigma_{max}$ or K_{min}/K_{max})
P	probability, 3 parameter-Weibull-distribution (Master curve concept, Eq. (27))
R_{eL}	lower yield strength (materials showing a Lüders' plateau)
$R_{p0.2}$	0.2 proof strength (materials without Lüders' plateau)
R_m	tensile strength (tensile test)
$t_{8/5}$	cooling time from 800 °C to 500 °C
T	plate thickness
T_p	peak temperature during welding
W	specimen width
Y	geometry function (stress intensity factor solution)
Z	reduction of area at fracture
α	weld flank angle
α_g	constraint factor in Eqs. (12) and (13)
ρ	weld toe radius
Δa	crack extension
Δa_{LC}	crack extension at the transition from the *short* to the *long* crack
ΔK	K-factor range ($K_{max} - K_{min}$)
ΔK_{eff}	effective or crack closure corrected K-factor range
ΔK_{th}	fatigue crack propagation threshold
$\Delta K_{th,eff}$	intrinsic fatigue propagation threshold
$\Delta K_{th,LC}$	fatigue propagation threshold in the long crack regime
σ	stress
σ_a	stress amplitude (= ½ $\Delta\sigma$)
σ_{max}	maximum stress in the fatigue cycle
σ_{open}	stress in the loading cycle above which the crack is open
σ_Y	yield strength, general term
σ_w	fatigue limit (stress amplitude) at $R = -1$