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The development of a damage tolerance concept for railway components and its demonstration for a railway axle

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Abstract

A draft procedure for damage tolerance analysis of railway components is presented and illustrated by a case study on a railway axle. The scheme is based on the recently developed European flaw assessment procedure SINTAP, the NASGRO/ESACRACK procedure for fatigue crack extension and other documents. As the result of the worked example the crack size was quantified which has to be detected in non-destructive testing if the inspection interval is fixed by an existing maintenance plan. The resulting numbers are aimed at illustrating the method and cannot be used for industrial implementation without appropriate modification.

Keywords: Railway axles; Damage tolerance; Fatigue crack extension; SINTAP; NASGRO; ESACRACK

1. Introduction

An introduction to railway applications of fracture mechanics was given in the review paper in [1] which, among other items, also dealt with problems of railway axles. Here, a more detailed discussion of this topic will be provided along with some aspects of a draft general scheme for damage tolerance of railway components prepared for DB (Deutsche Bahn) [2] and a calculational exercise on an axle. Note, that the latter is part of ongoing work. Therefore, the numerical results presented here aim at demonstrating the principles of a damage tolerance analysis of railway axles rather than providing realistic quantitative information for an immediate implementation under practical conditions.

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Nomenclature

a	crack depth
a_o	initial crack depth (NDI detection limit) for a damage tolerance analysis
c	surface crack length of a semi-elliptical surface crack
c_o	initial crack length for a damage tolerance analysis
C, n, p, q	fit parameters in the NASGRO equation (Eq. (5))
D_i	inner diameter of the axle section containing the crack
D_o	outer diameter of the axle section containing the crack
E	Young's modulus
E'	effective E ($= E$ for plane stress; $= E/(1-\nu^2)$ for plane strain)
f	crack opening function (Eq. (7))
f_o, f_1, f_2, f_3	geometry function (Eq. (11), Appendix B)
F	force
F_b	geometry function for global bending (Eq. (11), Appendix B)
F_Y	yield load (Eq. (19))
$f(L_r)$	plasticity correction function of the crack driving force (Eq. (18), Appendix C)
J	J-integral
K	stress intensity factor (K factor)
K_{Jc}	fracture resistance of the material formally written in terms of K
$K_{Jc,d}$	design value of the fracture resistance for a certain failure probability
$K_{Jc(med)}$	medium value of the fracture resistance of 1T specimens (thickness $\approx$ 25 mm) (Eq. (1))
$K_{Jc(med)x}$	medium value of the fracture resistance in the component with the crack front length ℓ_o (Eq. (2))
K_{max}	maximum K factor within a load cycle
K_{min}	minimum K factor within a load cycle
K_o	scaling parameter of the Weibull distribution of the fracture resistance (Eq. (3))
K_{op}	opening stress intensity factor, above which the crack is open
K_p	plasticity corrected crack driving force in terms of K (Eq. (18))
K_I	mode-I stress intensity factor
ℓ_o	crack front length in a 1T specimen ($\approx$25 mm)
ℓ_x	crack front length in the component (Fig. 8)
L_r	measure of the ligament yielding (Eq. (19))
m	shape parameter of the Weibull distribution of the fracture resistance (Eq. (3))
M_m, M_b, Q	geometry functions (Eq. (10))
M_b	bending moment (Eq. (12))
N	number of applied fatigue cycles
n, p, q	fit parameters in the NASGRO equation (Eq. (5))
P_f	failure probability (Eq. (3))
POD	probability of crack detection in non-destructive inspection (Fig. 11)
POND	probability of non-detection (Fig. 18)
Q_1, Q_2	vertical forces acting at both wheels (Fig. 4)
R	stress ratio ($= K_{min}/K_{max}$)
T	wall thickness of the axle section containing the crack
T	temperature
T_o	transition temperature of the *Master Curve* concept (Eq. (1))