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Assessment of mixed mode crack propagation of crane runway girders subjected to cyclic loading

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ABSTRACT

Crane runway girders are subjected to travelling wheel loads resulting in mixed mode crack tip loading. The paper addresses the assessment of crack propagation of crane runway girders being travelled over by wheel loads. Fractographic investigations of crack surfaces show shear mode crack growth and scabs due to friction between the crack flanks. Crack growth rates for steels subjected to tensile mode crack growth are evaluated. Stress intensity factors of crane runway girders under cyclic loading are obtained by numerical investigations. Numbers of cycles of crack growth are calculated by use of the shear stress intensity factor K_τ.

1. Introduction

Crane runway girders are subjected to cyclic loading by travelling wheel loads during the operation of the crane. These crane runway girders are usually realized by means of rails which are welded on the main structure in light and medium service [1], Fig. 1. As a consequence of geometrical and process tolerances during the production process of the crane runway girders, a gap can arise between welded rail and girder. This results in sharply notched weld geometries. Thus the rail welds are located in highly fatigue stressed areas due to the given structural reasons.

The local stress state mainly arises due to the travelling wheel load consisting of a local compression stress $\sigma_{z,local}$ directly located beneath the wheel, Fig. 2. The local shear stresses $\tau_{xz,local}$ act out-of-phase during the wheel load passage. Thus crane runways are subjected to non-proportional cyclic loading. The local stress state is superimposed both on global stresses and welding residual stresses. Stress concentration due to the weld geometry and microstructure occurs for the given structural detail [1,2].

Numerous engineering components such as railway systems [4], bearings [4] or crane runway girders are subjected to rolling contact fatigue (RCF) due to travelling wheel loads. As a consequence, mixed mode crack tip loading occurs causing fatigue crack growth. Two failure modes can be separated by the direction of crack growth [5]: mode I controlled (tensile mode) and mode II controlled (shear mode) crack growth, see Fig. 3a. RCF causes non-proportional mixed mode crack tip loading [6] and shear mode growth [7–10] due to cyclic shear components. Traditional fracture mechanic concepts dealing with tensile mode crack growth are thus not applicable [7,11]. One of the reasons is the compressive stress field directly below the wheel load suppressing tensile mode crack growth [12,13].

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Nomenclature

a	crack depth
a_0	initial crack depth
a_w	weld size
c	half crack length (at surface)
C	empirical constant of NASGRO and Paris equation
E	Young's modulus
f	crack opening function of NASGRO equation
F	wheel load
K	stress intensity factor
K_I	mode I stress intensity factor
K_{II}	mode II stress intensity factor
K_{III}	mode III stress intensity factor
K_c	fracture toughness
K_{max}	maximum stress intensity factor
K_{min}	minimum stress intensity factor
K_{th}	threshold stress intensity factor
K_σ	normal stress intensity factor
K_τ	shear stress intensity factor
m	empirical constant of NASGRO and Paris equation
N	number of cycles
N_1	number of cycles until first through-thickness crack
N_2	number of cycles until complete separation of rail
N_B	total number of cycles = $N_i + N_p$
N_i	number of cycles to crack initiation
N_p	number of cycles of crack growth
p	empirical constant of NASGRO equation
q	empirical constant of NASGRO equation
R	stress intensity factor ratio (K_{min}/K_{max})
t	time
v	speed
x, y, z	Cartesian coordinates
α	constraint factor
ΔK	cyclic stress intensity factor range ($K_{max}-K_{min}$)
γ	stress intensity factor ratio K_{II}/K_I
ν	Poisson's ratio
φ	(global) crack propagation angle
σ	normal stress
σ_y	yield stress
$\sigma_{z,local}$	local compression stress caused by wheel load
τ	shear stress
$\tau_{xz,local}$	local shear stresses caused by wheel load
θ	(local) crack deflection angle

Abbreviations

AIM-Life	Advanced Integrated Multiaxial Life
cal	calculated
C(T)	compact tension
exp	experimental
FE(M)	finite element (method)
FP	fatigue parameter
IIW	International Institute of Welding
LEFM	linear elastic fracture mechanics
MPA	Materials Testing Institute University of Stuttgart
RCF	rolling contact fatigue
SEM	scanning electron microscope