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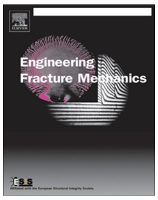

Calculation of crack driving forces of surface cracks subjected to rolling/sliding contact

M. Kráčalík [a],*, W. Daves [a,b], T. Antretter [b]

[a] Material Center Leoben Forschung GmbH, Austria
[b] Institute of Mechanics, Montanuniversität Leoben, Austria

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A B S T R A C T

The paper deals with finite element computations of crack driving forces for a surface crack in a rail under cyclic elastic–plastic conditions during wheel/rail contact. A straight crack normal to the surface is investigated. Examinated are influences of wheel load, slip, residual stresses, crack lengths and mesh around the crack tip on the crack driving forces. The specific role of the plastic deformation during one rolling cycle and the resulting development of the crack driving force is discussed. The numerical verification of the configurational force concept is done by comparison with classical *J*-integral investigations using linear-elastic and elastic–plastic material properties.

1. Introduction

The investigation of the mechanisms of wear and damage of rails in the railway system is a vast topic and contains many mutually connected aspects. One damage mechanism is called rolling contact fatigue (RCF) and can be divided again into wear, spalling, pitting, head checks, squats etc. One main aspect of this work will be the investigation of crack growth in rails.

Rails are subjected to a heavy mechanical loading by a rolling/sliding wheel. The load parameters as e.g. normal load, slip velocity, wheel radius and contact geometry defined by wheel and rail profiles and the movement of the bogie play a key role for the service life of rails.

Rolling/sliding contact of the wheel along the rail produces a shear deformation in the surface layer of the rail. The shear deformation results especially from the traction force and leads to an anisotropic material orientation in a surface layer of the rail. Associated effects are a changing material microstructure, heat generation and damage. An additional aspect in the production of an extremely deformed surface layer is the surface roughness. The deformation due to rough contact contributes strongly to the amount of the plastic deformation calculated assuming flat surface contact mechanics in the outermost surface layer. This additional plasticity has to be regarded if the case of wear and crack initiation at the surface is of interest, see [1,2].

The prediction of crack growth and crack initiation saves costs in the maintenance of railway systems and plays a key role in the operational safety of the track. In the case of growing cracks rail maintenance such as grinding is expensive and shall be avoided or extended to longer cycles. Another interesting aspect for railway operators provides the possibility to predict damage resulting from the traffic and the type of cars and locomotives running on their tracks. It is planned to charge the

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* Corresponding author. Tel.: +43 384 245 922 78.
E-mail addresses: michal.kracalik@mcl.at (M. Kráčalík), werner.daves@mcl.at (W. Daves), Thomas.Antretter@unileoben.ac.at (T. Antretter).

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Nomenclature

w	deformation energy
J	*J*-integral
Γ	curve around the crack tip
ds	element on the curve Γ
J_{tip}	near tip *J*-integral
K_{tip}	near tip stress intensity factor
$\bar{u}$	displacement vector
$\overline{T}$	traction vector
$\underline{f}$	configurational body force for elastic material properties
$\underline{f}_{pl}$	configurational body force for plastic material properties
$\underline{\underline{C}}$	configurational stress tensor
$\underline{\underline{I}}$	unit tensor
ϕ	strain energy density
$\underline{\underline{F}}$	deformation gradient
$\underline{\underline{S}}$	first Piola–Kirchhoff stress tensor
$\nabla\underline{u}$	displacement gradient
$\underline{u}$	displacement
$\underline{X}$	position in the original configuration
$\underline{\underline{T}}$	Cauchy stress
$\underline{g}_i^I$	configurational force component at node*I*
$\underline{\underline{N}}^I$	matrix with shape function corresponding to the node*I*
$\underline{\underline{N}}^I_{,X_j}$	gradient matrix
$\underline{u}_{,X_j}$	displacement gradient at node*I*
E	Young's modulus
ν	Poisson number

track users according to their track damage produced. For this purpose a matrix is of interest which maps axle-loads, wheel profiles, bogie-behaviour to the damage obtained in the track.

Parameters such as normal load, slip conditions, slip parameters, residual stresses, crack length have to be examined in order to predict their influence on crack growth. The used crack models are based on a two-dimensional description including a wheel/rail rolling/sliding contact including stick–slip behaviour. As finite element models are developed describing the cyclic elastic–plastic material properties of a rail, crack models need to be used which can include these features.

The numerical evaluation of crack driving forces is in this work conducted using the classical *J*-integral implemented in finite element programs as well as the newly developed configurational force method. In both methods the elastic–plastic material properties of rails and wheels can be described with the restriction for the *J*-integral that it is based on a non-linear elastic description of the elastic–plastic material behaviour, which is not suitable for quantitative cyclic investigations, since in rolling–sliding contacts are plastic cycles and non-proportional loading and unloading in many cases dominant, see [3–6]. The results show that in the case of rolling/sliding contact loading the configurational force method is more suitable as a comparison of the results obtained from the classical *J*-Integral method vs. the new implementation of the configurational force method reveals. However, for the first loading cycle the *J*-integral is suitable for evaluating parameters and for comparison to literature results. In the later part of the work results of the configurational (or material) force concept show the influence of the method.

A main task of the work at hand is the evaluation of different model assumptions such as the influence of the type and size of the mesh and elements around the crack, the type of calculating the crack driving force and the effect of residual stresses. For these purposes and to allow comparison with other literature the crack driving forces are calculated using the classical *J*-integral. It is shown that for the elastic case the results are equal to those obtained using our configurational force implementation and thus validates its implementation.

In this work the following simplifications in the finite element model are made:

- The finite element crack model is restricted to a two-dimensional description,
- the external loading and prescribed slip are constant during the cycles,
- a single straight crack is modelled in the middle of the rail,
- the rolling wheel is accelerated using a tangential force to generate slip conditions,
- the surface is assumed to be flat without roughness,
- between the rotating wheel and the rail a Coulomb friction law is assumed.