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Effect of residual stresses on the fatigue lifetime of railway axle

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Abstract

The operation of railway axles should fulfill at least two main demands: safety and low operation costs. A significant part of operation costs is given by the length of regular inspection intervals which should reveal potential fatigue cracks in railway axle. The detection of cracks is of a probabilistic nature, therefore their detection is not ensured in all cases. For the safe operation of trains, an existence of potential initial crack should be considered on the axle surface and residual fatigue lifetime should be conservatively determined for this case. Reliable procedure of residual fatigue lifetime estimation should take into account real axle geometry, material characteristics and loading of the railway axle. This paper shows methodology for determination of residual fatigue lifetime (RFL) based on the fracture mechanics approach, taking into account real spectrum of the loading cycles, existence of press-fitted wheels and surface residual stresses given by the thermo-mechanical surface treatment of the railway axle. It is demonstrated that the effect of the residual stresses is significant and should not be neglected in the numerical estimation of residual fatigue lifetime of the axle.

Keywords: Railway axle; residual fatigue lifetime; residual stresses; inspection intervals; numerical simulation

1. Introduction

Ones of the critical components of trains are railway axles, see references Zerbst et al. (2005), Zerbst et al. (2013) and Zerbst et al. (2013b). It is known that railway axles can include defects like cracks or surface scratches, which can lead to fatigue crack initiation and propagation. Unfortunately, the detection of such (in certain cases

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dangerous) cracks is not possible in all cases. The longer crack, the higher probability of its detection exists, see Benyon and Watson (2001). However, the detection does not depend only on; the size of the crack, but also on the position of the crack and non-destructive testing (NDT) method used. Due to this fact it is necessary to know the length of crack which is detected with required probability. By assumption of initial crack length in the axle it is possible to setup frequency of regular inspections including NDT method, see references Zerbst et al. (2011) and Zerbst et al. (2013). If the inspection intervals are shorter than the time necessary for crack propagation from initial size up to critical one, the operation of the railway axle is safe. Nevertheless, if regular inspections are performed unnecessary often, the costs for axle (train) operation will increase. Nowadays, the regular inspection intervals are often verified by numerical simulations, see references Luke et al. (2010), Luke et al. (2011), Smith (2000), Zerbst et al. (2005) and Zerbst et al. (2013). However, it seems that in many cases numerically estimated residual fatigue lifetime (RFL) of railway axles is still different in comparison to the experimentally determined one. One important factor influencing fatigue crack propagation in the railway axle is level of residual stresses. Especially compressive residual stresses close to the surface of the axle can effectively retard fatigue crack propagation from initial surface defect and consequently extend the RFL of the axle, see e.g. Regazzi et al. (2014). The aim of this contribution is to quantify the effect of the residual stresses (based on numerical simulations) on RFL of the railway axle.

Nomenclature	
a	crack length
a_0	initial crack length
b	crack width
C, n, p	material constants of NASGRO relationship
k	dynamic coefficient
K_B	stress intensity factor corresponding to bending load
K_I	stress intensity factor (general expression)
K_{max}	maximum of stress intensity factor in load cycle
$K_{max,th}$	threshold value in K_{max} expression
K_{min}	minimum of stress intensity factor in load cycle
K_{PF}	stress intensity factor corresponding to press-fit load
K_{RS}	stress intensity factor corresponding to residual stress
ΔK	stress intensity factor range
L	distance from axle surface (depth)
R	stress ratio
v (da/dN)	fatigue crack propagation rate
σ_{ax}	residual axial stress
EA4T	steel grade
SIF	stress intensity factor
RFL	residual fatigue lifetime
(B)	bending
(PF)	press-fit
(RS)	residual stress

2. Estimation of residual fatigue life of railway axle with consideration of residual stresses

Presented numerical estimation represents enhanced version of already published procedure (see Náhlík et al. (2017)) for determination of RFL of railway axle. The difference is in implementation of influence of residual stresses, which are induced during manufacturing process, to the procedure of RFL estimation. Fig. 1 shows considered railway axle. In this case the critical initial crack location was determined close to the railway wheel seat, see Fig.1. The manufacturing process of railway axle usually contains surface treatment of the axle. Compressive residual stresses of extreme magnitudes usually between 20-60 MPa are developed after application of thermo-mechanical treatment. The compressive residual stresses close to the axle surface can effectively retard fatigue crack propagation and consequently extend the RFL of the axle. Typical distribution of the axial residual stresses is shown in Fig. 2.