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Wear and RCF assessment in switch rails for different materials

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Abstract

Switch rails are severely loaded components in the railway turnout. This work presents a numerical framework to assess the wear and rolling contact fatigue (RCF) for two different pearlitic switch rail materials. Firstly, a cyclic finite element analysis (FEA) is performed calculating the local loads during the first contact of different wheels on the switch rail. Secondly, local wear and RCF models for the investigated steel grades R350HT and 400 UHC® HSH® are determined and their output is visualized in damage maps. After that, the local contact parameters maximum contact pressure, creepage and contact length are extracted from the FEA considering these different wheel profiles and different rail materials. The calculations deliver local contact loads on the switch surface, which are marked in the damage maps. This allows the comparison of R350HT and 400 UHC in relation to their damage susceptibility. Both show a very similar damage response to the contact loading in the switch rail. Wear and surface RCF are the dominating damage patterns. Subsurface RCF is only predicted for some local cases. In total, 400 UHC® HSH® exhibits a higher resistance against wear and RCF. Regarding the wheel types, the worn wheels are identified as most critical for the damage in the switch rail.

Keywords: switches and crossings, rolling contact fatigue, wear, finite element analysis

1 Introduction

Turnouts are key parts of the railway network as they guide trains between different tracks [1,2]. Figure 1 shows the layout of a fixed turnout and its components. The switch rails connect the switch panel at the front of the turnout and the crossing panel at the rear [3]. Due to the direction change of the train when passing the turnout in the diverging route, high lateral and creep forces are generated between wheel and rails [4,5]. In the contact, these forces induce locally high contact stresses and cause slip or creepage. This concentrated contact loading leads to rail degradation reducing the component lifetime, affecting the traffic safety and requiring maintenance actions from track operators [2]. Three distinctive interacting damage mechanisms are observed: plastic deformation, rolling contact fatigue (RCF) and wear [1,2].

This numerical work estimates the wear and RCF behaviour of two different fine-pearlitic rail steels (R350HT and 400 UHC® HSH®) in the switch panel of a standard 60E1-500-1:12 turnout. To this end, a finite element analysis is performed to calculate the local contact loads during the first contact of the wheel on the switch rail, adopted from [5]. These contact loads are extracted to investigate the local damage near the surface of the switch rail. The damage of the two materials is estimated and compared for the calculated loadings. The analysis is based on the approach proposed in [6],where an assessment tool is described which allows the evaluation of damage in contact loaded components.

In particular, the maximum contact pressure p_{max}, creepage c and contact length $2a$ are calculated along the switch rail for the passage of different wheel types. This procedure delivers the p_{max}, c and $2a$ values along the switch rail. These variables are the basis for the evaluation of local wear and RCF at different position of the switch rail. The damage models comprise the shakedown theory to estimate the risk for surface cracks, the Dang Van criterion for subsurface cracks and the Archard equation for wear estimation. In wear and RCF maps, the material-dependent damage regimes are visualized using p_{max}, c and $2a$ axes. These maps provide a tool to estimate the contribution of different wheel profiles on the overall degradation of the switch rail, identify critical wheel types and assess standard and new materials.

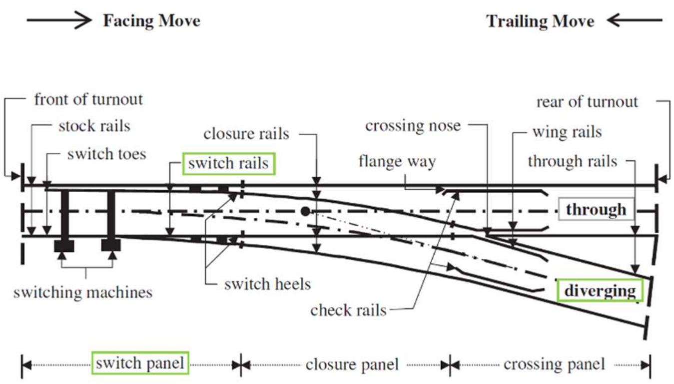

Figure 1: Schematic overview of the components of a fixed turnout (adapted from [3]).

2 Methods

The numerical approach to assess the wear and RCF behaviour consists of three major steps, as shown in Figure 2. Firstly, the contact loads along the switch rail are evaluated from the local dynamic finite element model adapted from Velic et al. [5]. A total of 100 load cycles is simulated with ten different wheel types including measured so-called unworn, worn and hollow profiles. An elastic-plastic Chaboche-type material model with material parameters calibrated for R350HT and 400 UHC® HSH® under multiaxial loading conditions is applied for the rail part to account for the plastic deformation. For each wheel type the contact parameters p_{max}, creepage c and contact length $2a$ are determined in 15 equidistant cross-sections along the switch rail model. Each p_{max}, c and $2a$ parameter set defines one working point (contact load representation) on the switch rail.
Secondly, the damage maps for the R350HT and 400 UHC® HSH® are determined following the approach presented in Schnalzger et al. [6]. The local damage models are based on Archard´s wear model [7] as well as an RCF model for surface and subsurface cracks adopted from Ekberg et al. [8]. Carter´s creep force model is applied to obtain a relation between the traction coefficient and creepage, which is required to implement the aforementioned damage models. A detailed description about the implementation process is found in [6]. Table 1 summarizes the most important system constants and assumed material properties. The latter are obtained from literature as well as from own material tests.
Thirdly, the working points of the different wheel types evaluated within the first step are marked in the wear and RCF maps. These maps visualize the working point location within the damage regimes. For the assessment of the damage for each wheel the following indices or values are used. The fatigue indices indicate the probability for crack initiation at or below the surface. The wear depth is calculated but considers only one passage of the wheel neglecting its lateral position. Hence, the wear depth is appropriate for relative comparisons but not intended for quantitative predictions.

	Property			
System	Normal force F_N	125 kN		
	Vehicle velocity [km/h]	70 km/h		
	Coefficient of friction [-]	0.35		
	Wheel rolling radius [mm]	518		
		R350HT	400 UHC® HSH®	Literature/Comments
Material	Shear yield limit k [MPa]	323	338	estimated from tensile strength as $\sigma_y/\sqrt{3}$ [9]
	Shear-torsion fatigue limit τ_f [MPa]	307.2	431*	*conservative estimation from ultimate tensile strength [10]
	Dang Van material parameter α_{DV} [-]	0.399	0.24*	
	Ratio wear coefficient and hardness for severe wear regime K/H [1/GPa]	1.12e-3	1.02e-3	[5]

Table 1: System and material properties applied for the assessment of the R350HT and 400 UHC® HSH® in the switch rail.

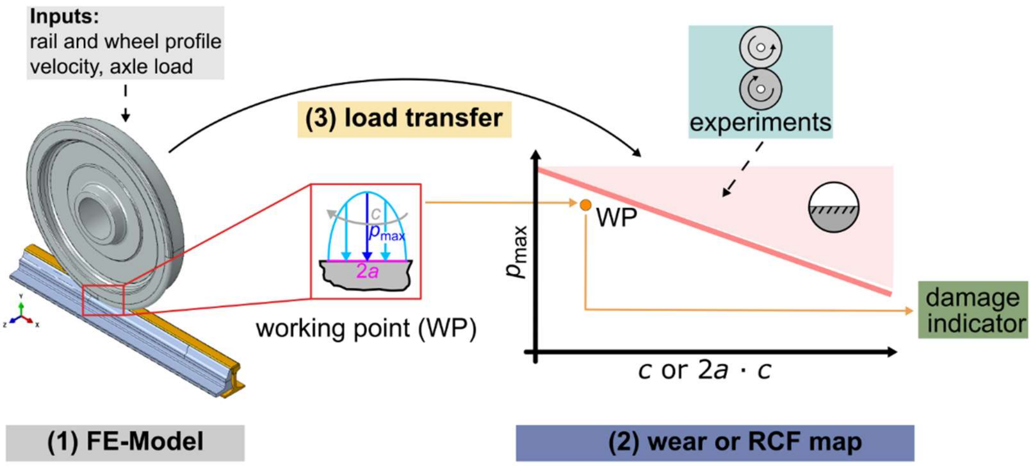

Figure 2: Overview of the numerical approach to assess the wear and RCF behaviour of switch rail materials.

3 Results

The wear and RCF maps for R350HT and 400 UHC® HSH® are presented in Figure 3 (a) and (b), respectively. The RCF map is divided into four different regimes, which are differently coloured. In the white-coloured lower pressure regime, no crack initiation is expected. The yellow-coloured region at intermediate pressures indicates the risk of crack initiation at the surface. In the salmon-coloured area on top, cracks might initiate at surface as well as at subsurface positions. At low creepages and high contact pressures in the magenta-coloured area subsurface crack initiation is predicted. The grey horizontal and vertical lines indicate the different Archard wear regimes for a fixed train velocity of 70 km/h. The wear maps on the right hand side are exclusively valid for the stated constant wear coefficient of $4x10^{-3}$, which is a typical mean value for the severe wear regime reported in literature [5,7]. The presented wear depths occur after one passage of the contact patch and are intended for relative comparison of the severity of different working points with respect to wear. Absolute wear predictions are out of the scope of the present investigations. However, the stated wear depths are appropriate for them as well, if the lateral contact positions of the wheel-rail contact are considered for the wear accumulation.

The symbols plotted in the maps in Figure 3 indicate the working points computed along the switch rail for the different wheel types. The unworn wheel (green points) corresponds to the nominal wheel with the standard profile S1002. The remaining nine worn profiles are clustered with circles regarding their profile characteristics (worn and hollow wheels). The profile shape of the unworn, worn and hollow wheel types (WT) are shown in Figure 4 as function of the wheel radius and width.

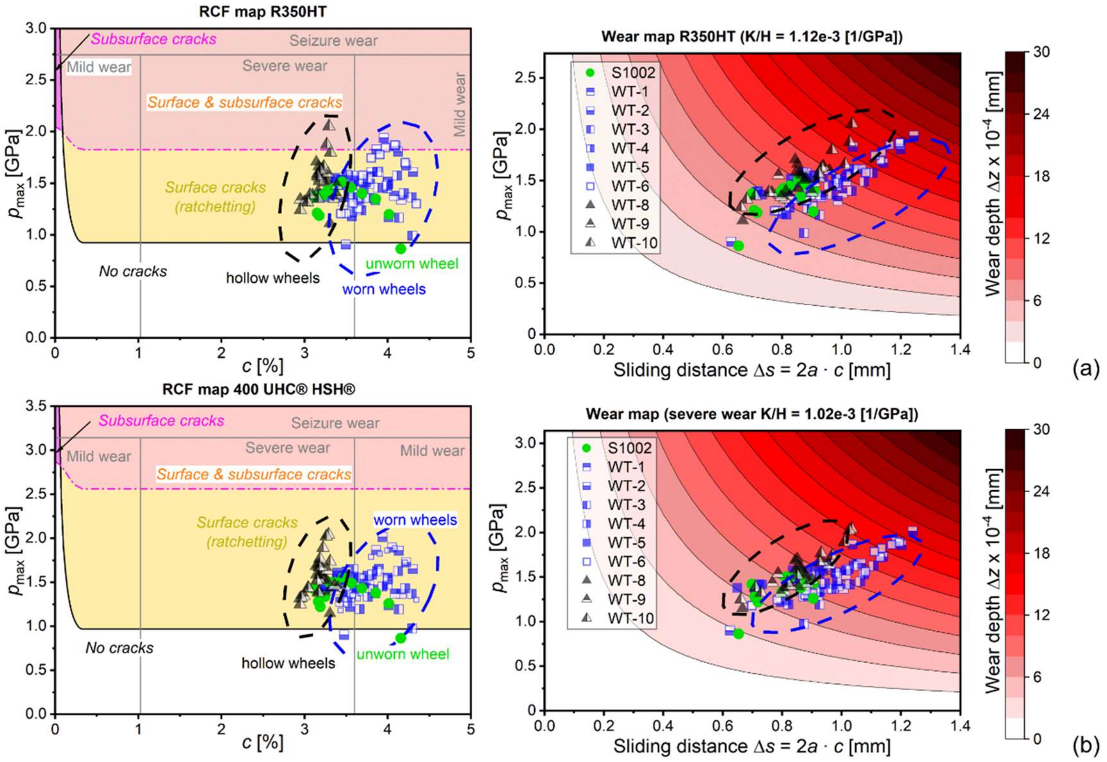

Figure 3: RCF and wear maps for (a) R350HT and (b) 400 UHC® HSH® visualizing the material-dependent damage regimes and working points for ten different wheel profiles (symbols).

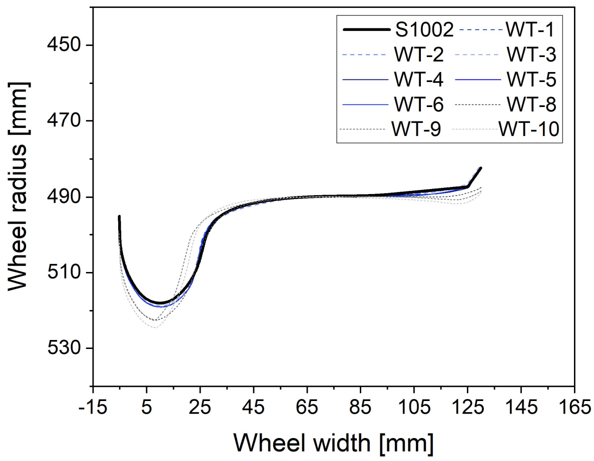

Figure 4: Profile shapes of the unworn, worn and hollow wheel profiles considered for the damage assessment.

4 Conclusions and Contributions

The wear and RCF maps present the material-dependent damage response under contact loading in terms of p_{max}, c and $2a$. By transferring the contact loads from the finite element vehicle-track model to these maps as working points the damage behaviour is visualized. For the investigated pearlitic switch rail materials and wheel types the following main conclusion are drawn:

- R350HT and 400 UHC® HSH® exhibit a very similar material response to contact loading. The lower limits for surface RCF are in the same range. With respect to wear and subsurface RCF, 400 UHC® HSH® shows a better performance compared to R350HT.
- In general, wear and surface RCF are the dominating damage mechanisms degrading the switch rail.
- Regarding wheel type dependent damage, the following tendencies are observed: For the worn wheels, the highest creepages are observed and the corresponding working points lie near the boundary between the severe and the mild wear regime. With respect to RCF, a probability for crack initiation at the surface is given. For some local contact loads, also subsurface RCF is expected. The hollow wheels lie in the severe wear regime due to lower creepage values. However, due to higher p_{max} values higher wear rates occur. The nominal wheel profile S1002 lies in a damage regime between the on pertaining to hollow and the one pertaining to worn wheels at the lower end of the contact pressure range.

The application of the wear and RCF maps to the switch rails allows to reliably assess different materials in track operations. Critical loading conditions can be identified and damage indicators for specific working points are presented in the maps. Such indicators are a necessary input for long-term damage prediction considering different vehicle types and traffic scenarios. An advantage of the presented concept relative to existing approaches is the option to use load input from various sources such as finite element simulations, multi body system simulations or from measured data.

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