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Development of white etching layers on rails: simulations and experiments

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ABSTRACT

White Etching Layers (WELs) on rails owe their name to the white appearance after etching with Nital. WEL is very often linked with rail defects like Squats and are said to partly consist of martensite, which indicates thermal effects. On this account, temperature simulations on and below the rail surface in the wheel-rail contact zone were done for a given set of parameters. The simulation results reveal that the austenitisation temperature of steel – necessary for the development of martensite – is reached under certain conditions. Validation tests on the full-scale wheel-rail test rig at voestalpine Schienen GmbH (Leoben / Austria) produced WELs and showed a good agreement with the simulation results. The presented and validated model can e.g. be used to enhance traction and braking control systems to reliably avoid the development of WELs in operation and to reduce according wheel-rail defects (e.g. Squats).

1. Introduction

Squats (Fig. 1) are defects on rails causing high maintenance costs [1–6]. In the worst case, these defects can lead to rail fracture. Squats have been observed for a long time, for example in the 1950s in Japan as black spots, in the 1970s in Great Britain or in the 1980s in Japan again at the Tokaido Shinkansen line, called there “Shinkansen Shelling”. To prevent the development of Squats, it is of great interest to understand the mechanisms behind its initiation and propagation. Squats are often linked to White Etching Layers (WEL), a hard (up to 600–750 HB [7]) and brittle surface layer with a typical thickness up to 100 μm frequently found on rails in operation more or less independent of the operating conditions [6]. WELs are often shown to consist of martensite [8]. A typical WEL is shown in Fig. 2.

There are mainly two approaches to explain their development [8–11]. The first theory assumes that severe plastic deformations at temperatures below the austenitisation temperature cause the formation of WEL (friction-martensite). The second one supposes that WEL develops due to heating above austenitisation temperature followed by rapid cooling (thermal-martensite). Under normal conditions, the austenitisation temperature of steel is around 720 °C. Due to multiaxial compression it can be lower [8].

The goal of this work is to get a better understanding of the development of thermal-martensite and to determine conditions that are necessary to reach the required temperatures. Furthermore, several experiments were performed at the full scale wheel-rail test rig from voestalpine Schienen GmbH in Leoben/Austria to validate the simulation results.

2. Simulation model

The temperature distribution within the wheel-rail contact area as well as below the surfaces is mainly influenced by the creepages in combination with the existing traction coefficient. Thus, for the calculation of temperature distributions the so called Extended-Creep-Force model (ECF) was applied because it's capability to take into account this interaction appropriately [13,14]. Contrary to many state of the art models [15–18], this is achieved by consideration of an elastic-plastic layer between wheel and rail, a so called Third Body Layer (3BL). The material properties of this layer depend on local normal stress and temperature, which, in turn, have a high influence on the traction.

In Fig. 3, traction coefficient characteristics calculated with the ECF-model are compared with results from vehicle tests at different vehicle speeds v_v. First, they show and increasing behavior until a certain creepage where the maximum traction occurs. After that maximum, the traction coefficient decreases because of the influence of the temperature. The maximum depends on the

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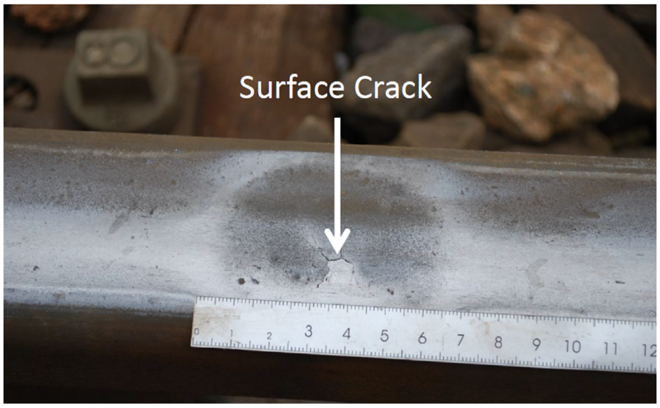

Fig. 1. A Squat defect on a rail. The typical lung like shape of the indentation is visible. The marked V-shaped surface crack is also a characteristic of Squats.

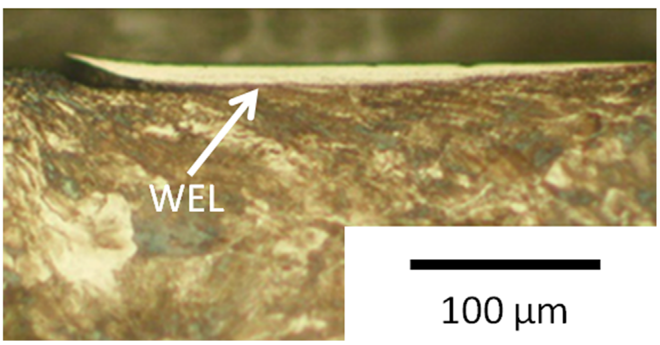

Fig. 2. Cross section of a rail from operation with a WEL on the surface [12].

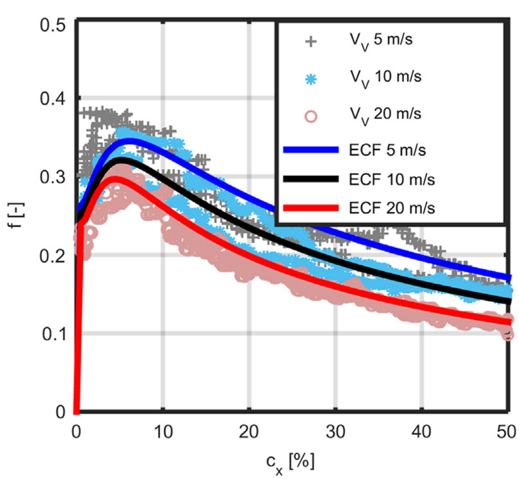

Fig. 3. Influence of the creepage on the traction coefficient for different speeds v_v from vehicle tests compared to results from ECF-model [13].

vehicle speed. At higher speeds, less creepage is needed to achieve the same frictional power density and, thus, the same temperature. The model was calibrated and validated by several test rig experiments and vehicle test and shows generally a good agreement with experimental data.

The ECF-model has a modular structure depicted in Fig. 4. Normal stress (p_n), contact geometry, environmental temperature, creepage, vehicle speed and material constants are input parameters. They are used in the 3BL model to calculate tangential stresses (τ). Then, the temperature model uses the stresses to calculate the local frictional power density and subsequently, the surface temperature (T). This new surface temperature affects the 3BL properties and, thereby, the tangential stresses. The iteration

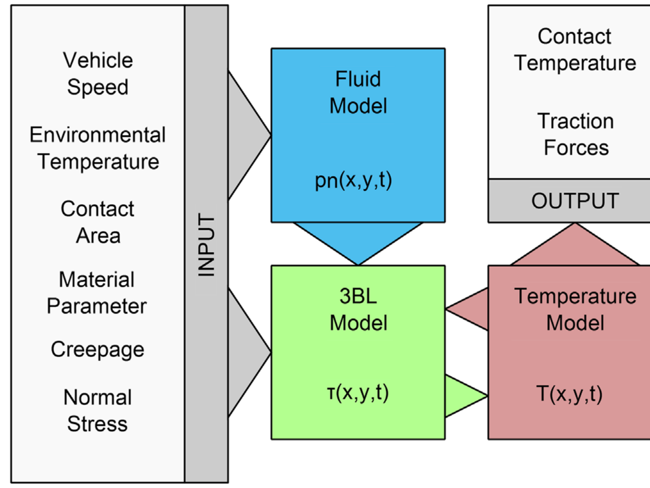

Fig. 4. The structure of the ECF-model.

continues until the difference between the surface temperatures calculated in two sequential iteration steps is within a certain prescribed range.

The calculation of the surface temperature follows the analytical approach published by Ertz and Knothe for the assumption of one dimensional heat flow [19] which is valid for most operating conditions [20].

The local calculations are based on a discretization of the elliptic contact patch according to Hertzian theory with the semi axes a and b. The local frictional power density is assumed to stay constant within a discretization element. The semi axis a is always oriented into the longitudinal direction of the rail x while the direction of the semi axis b is perpendicular to it.

3. Simulation results

In this section, some temperature influencing parameters are investigated. For the formation of thermal martensite, temperatures above the austenitisation temperature are necessary. Under normal conditions, the austenitisation temperature of steel is around 720 °C. As a first step, it was investigated, whether such high surface temperatures are achievable (Section 3.1). Therefore the surface temperature T_{max} as a function of vehicle speed v_v and creepage c_x was calculated with the ECF-model. Next, the influence of the contact patch size and the influence of the normal load F_N on the surface temperature were analyzed. In Section 3.2, the local temperature distribution below the surface will be regarded. Furthermore, the influence of the vehicle speed on the heating and cooling time of the temperature on and below the surface is investigated. It should be mentioned here that in this work negative creepage means accelerating wheel.

3.1. Maximum surface temperature

Fig. 5 shows the maximum surface temperature for a normal load of $F_N = 110$ kN. The semi axes of the contact ellipse are $a = 8$ mm and $b = 4$ mm (standard values). The results show that temperatures of $T_{max} = 720$ °C are possible with the selected simulation parameters. In this figure it is also visible that higher creepages lead to higher temperatures for a given vehicle speed due to higher frictional power density. The same is valid for increasing the vehicle speed at a constant creepage. The surface temperature approaches a limit of around $T = 1050$ °C according to the ECF-model due to the interaction of the traction coefficient and the temperature. This is the expected physical behavior and