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On the variations of white etching layers on railway wheels and the possibilities of imitation in a laboratory

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Abstract

Within this paper, different variations of white etching layers (WELs) detected on a railway wheel from service are investigated. Brightest appearing microstructures, after etching with Nital acid, show a fine mesh structure and high hardness values of ~ 6 GPa. It is concluded that such microstructures can defined as virgin WEL, where no thermal or mechanical load affected the WEL after its formation. Further WEL variations with lower hardness values and differences in the microstructural characteristics are presented. To imitate these microstructure variations in a laboratory, which is vital for verifiable testing like 2-disc experiments, a possibility of using a laser treatment and a twin disc tester is presented. Based on the commonly known formation process, the laser treatment pictures the thermal loading on the initial microstructure, whereby the twin disc tester is used to introduce a mechanical loading. Results show good similarity to the WEL from field in terms of microstructural characteristics and obtained hardness. Hence, the combination of the presented methods outpoints a promising possibility to create reproducible and realistic WEL microstructures.

Keywords: rail-wheel contact, near-surface microstructure, white etching layer, laser treatment, twin disc tester, electron microscopy

1 Introduction

White etching layers (WELs) are frequently observed on both wheel and rail surfaces. The name originates from the fact that such layers appear white after etching with an ethanol nitric acid. The importance of WELs in terms of crack initiation sites is unquestionable [1]–[8], in contrast to their forming mechanisms still discussed extensively [9]–[14]. Some studies predict heating above austenitization temperature followed by rapid cooling as formation process [15]–[17], others claiming heavy plastic deformation as the reason [18]–[20] where cementite dissolves due to extensive stress and a nano-crystalline ferrite layer is built. However, the formation mechanism of WEL is probably a combination of both, rapid heating above a certain temperature with subsequent cooling and severe mechanical loading [21], [22]. Hence, a wide range of variations is reported with regard to the microstructural properties of WELs [12], [23]–[25]. Due to the complexity of thermal-mechanical loading in a rail-wheel rolling-sliding contact the induced WEL is a history- and location-dependent microstructure with unique properties. Different microstructural characteristics presumably reveal differences in mechanical properties, further, influence on crack initiation and growth. A common classification and consistent naming is missing at the present time.

Therefore, in this work three main zones along a railway wheel tread after service were analysed and detected variations of WELs were investigated in terms of microstructural characteristics by light optical microscopy (LOM), scanning electron microscopy (SEM) and electron backscatter diffraction (EBSD) measurements. In addition, nanoindentation measurements have been examined, to evaluate micro-mechanical properties of the WEL variations.

To understand the different variations of WELs on railway wheels better, a combination of twin disc experiments and laser surface treatments were executed to imitate the detected WELs from the field in a laboratory. The used methods are related to the mechanical loadings from rolling and the thermal loadings originating from sliding events. Lab-induced WELs are characterized by LOM, SEM, EBSD and nanoindentation and a comparison to WEL from field is presented

2 Methods

A railway wheel after nearly 200,000 km in service out of the wheel steel gradeER7 was provided by the Austrian Federal Railways Holding Stock Company and was analyzed within this work. Samples were prepared out of three different zones of the railway wheel tread surface (peripheral tread region, middle part, and close to the wheel-rim) to identify field-WELs. For the formation of lab-WELs two methods have been combined: The thermal loading was imitated by laser surface treatments executed with a Direct Diode Laser System (HighLight 8000D, Coherent, U.S.). A continuous rectangular laser spot was moved along the twin disc sample with a nominal continuous power output of 8 kW at a wavelength of 975 nm. The laser power output control was realised with an external mounted pyrometer (LPC03, Mergenthaler, Germany). It was set as single colour pyrometer with an emissions coefficient $\varepsilon = 0.7$. The mechanical loading was created by a twin disc test rig with a disc out of R260 rail steel running against an ER7 wheel steel disc. A normal force of 800 N was applied and the test was running with 1,000 rpm and a slip ratio of 1 %.

Metallographic samples of the field- and lab-WELs were prepared by embedding in conductive compounds, coarse grinding, 1 µm diamond fine polishing, and etching with ethanolic nitric acid (3% HNO3, 97% ethanol). The microstructure was studied by light optical microscopy (LOM) (Axio Imager M2m, Carl Zeiss AG, Germany) as well as scanning electron microscopy (SEM) (Jeol JIB 4700F, Jeol Ltd., Japan) equipped with a Schottky field emission gun. Prior electron backscatter diffraction (EBSD) measurements additional finish polishing for 10 min with colloidal Silica (<0.25µm) has been carried out. EBSD measurements were performed in the SEM with optimised electron beam conditions at 15 kV acceleration voltage and a probe current of 3.6 nA. EBSD results were analysed by evaluating the inverse pole figures (IPF), kernel average misorientation (KAM), grain average misorientation (GAM) and fractions of low- and high grain boundaries. Furthermore, nanoindentation measurements were performed with a Bruker Hysitron Triboindenter TI980 (equipped with a Berkovich diamond tip) with a peak-load of 5 mN.

3 Results

Various different field-WELs were identified by etching the cross-sectional samples, with variations in appearance (bright shining to brownish), thicknesses (20 – 600 µm) as well as microstructure. The WEL pictured in Figure 1a is about 30 µm thick and embedded in a SPD aligned microstructure. Figure 1b shows a main brownish appearing WEL identified within zone 3 of the wheel tread surface which is up to 500 µm thick. On top of this region, a brighter and thinner WEL seems to be evident. In some areas, the underlying material is a SPD microstructure, in others an almost not affected coarse ferritic-pearlitic microstructure. The thin and bright shining WEL reveals a fine meshed structure with some very small particles evenly distributed (Figure 1c). As a reference, Figure1d pictures the underlying SPD and aligned microstructure. The other thin (~20 µm) WEL investigated in Figure 1e looks more brownish. Indeed, the meshed network seems to be broken and spherodized in some areas (Figure 1e). This trend, the dissolution of the network structure, is more pronounced for the thick and even more brownish appearing WEL (Figure 1f). Almost no but parts of the mesh can be identified, in addition, spherodized particles in larger size can be seen. Nanoindentation results are presented in the related micrographs (Figure 1), where the hardness is increasing the brighter the WEL appears.

The imitation of WEL in a laboratory by the combination of laser treatments and twin disc experiments show good results concerning the comparability of the evolved microstructure. By applying different laser treatments, representing various thermal loadings by slip events in service, different variations of WEL can be produced. An exemplary LOM micrograph of a twin disc sample treated with two laser treatments is shown in Figure 2a. Multiple variations are produced by different sequences of laser treatments and twin disc experiments, as well as changing the amount of thermal loading by changing the laser input energy. The detailed microstructural investigations by SEM and EBSD indicate similar evolved microstructure and comparable nanoindentation hardness for certain variations of WELs on railway wheels (Figure 2b,c).

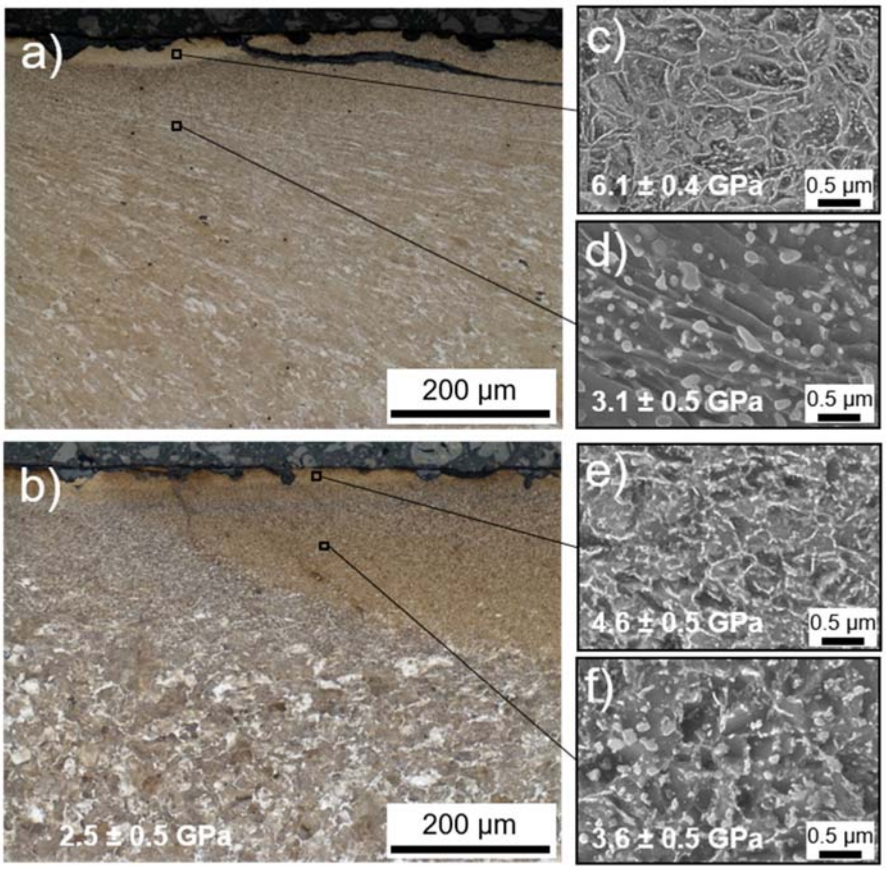

Figure 1: LOM micrographs (a-b) of the investigated field-WELs and referring high magnification SEM images (x10,000) (c-f).

4 Conclusions and Contributions

The analysis of a railway wheel after almost 200,000 km in service points out the complexity of their interpretation since the microstructural evolution is history- and location-dependent, influenced by a combination of thermal and mechanical loadings. Howsoever, investigations of variations of WEL-like regions, crucial for crack initiation and growth, were done by combination of microscopic analysis nanoindentation measurements.

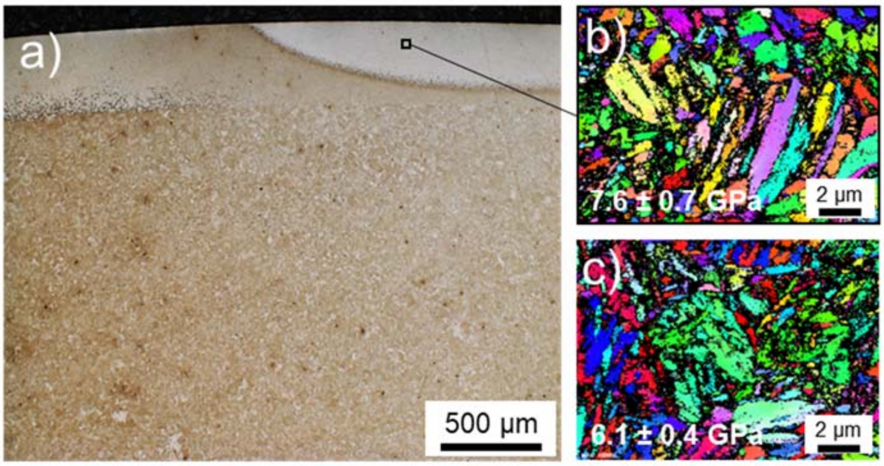

Figure 2: Lab-WEL by combined thermal (laser) and mechanical (twin disc) loading (a). Detailed microstructural comparison by EBSD indicates similar microstructure and comparable nanoindentation hardness of lab-WEL (b) and field-WEL (c).

Besides the currently missing common naming and categorisation, this work enables a ranking in terms of the predicted extent of their experienced thermo-mechanical loadings:

- The brightest appearing and thin WEL reveals a fine intact mesh structure and the highest hardness, suggesting a more virgin WEL with minor experienced loadings since formation, presumably resulting from a short slip event.

- The softest WEL shows a dissolved microstructure with spherodized cementite and looks brownish by LOM. It can therefore be concluded that this variation of WEL was formed due to severe thermal loading, as for instance hard braking of the wheel.

- Another WEL, situated on top of the large brownish WEL, reveals a mesh structure tending to be demolished with lower nanoindentation hardness. Therefore, it is assumed that it primarily has experienced mechanical loading since its formation, which probably was due to a short event of slippage.

Since the wheel-rail contact comes up with thermal and mechanical loadings, an attempt to imitate WEL on railway wheels is presented within this study by various combinations of laser treatments (thermal loading) and twin disc experiments (mechanical loading). Results indicate good correlation of the microstructural characteristic to the field-WELs, extensively analysed by LOM, SEM and EBSD measurements. In addition, nanoindentation measurements point out the micro-mechanical properties of the microstructures evolved and come up with comparative values. The study shows a promising method to imitate WELs on railway wheel materials in a laboratory originating from combined thermal and mechanical loadings.

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